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HUMAN RESOURCES

DEFINITION OF REQUIREMENTS FOR A
PERFORMANCE MEASUREMENT SYSTEM FOR C-5
AIRCREW MEMBERS

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This study identified and defined C-5 aircrew tasks and performances essential to the effective operation of the aircraft on a typical, representative mission. It described present capabilities of C-5 simulators to determine how these capabilities might be implemented or augmented for measuring crew performance. The results of the above efforts were synthesized into a description of the requirements for a C-5 aircrew performance measurement subsystem. The study also identified the applicability of these C-5 simulator performance measures to the airborne environment. The capabilities of the C-5 aircraft systems to provide necessary data are described, and the results are synthesized into a functional description for a C-5 inflight performance measurement system.

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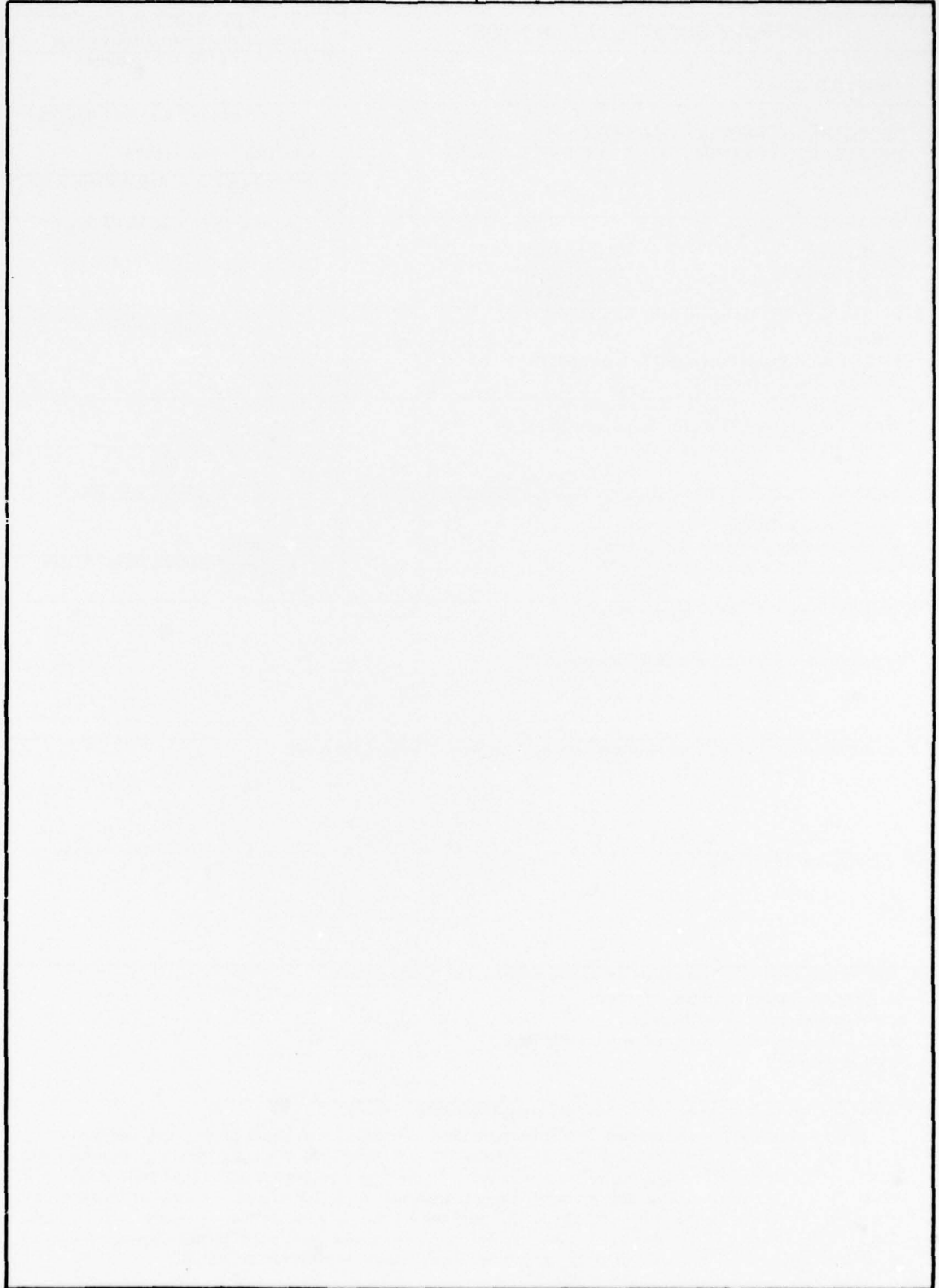
PREFACE

This report represents a portion of the research program of
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SECTION I

INTRODUCTION

Background

The last 30 years has witnessed substantial advances in simulation technology and increased implementation of these devices in both military and civilian aviation training programs. Initially, flight simulators were used primarily for cockpit familiarization and procedures training. As technology advanced, the scope of flight skills which could be trained in the simulator has increased dramatically and presently includes highly complex tasks, such as air-to-surface weapons delivery and air-to-air combat maneuvering. Such increased scope is primarily due to the advent of sophisticated motion and visual cueing systems and the use of high speed digital computers for their control. As flight simulation technology has increased, so have the associated costs. Due to these increased procurement and maintenance costs, there is a need to objectively document the effectiveness of present training devices and to evaluate proposed modifications in terms of their incremental training value. The requirement to document simulator training effectiveness points to the necessity of an objective performance measurement system.

There is a second trend which further reinforces the need for a objective measurement system. As simulator costs have increase, so have aircraft operating costs. In a staff study published in the summer of 1973 by the Office of Management and Budget (OMB), potential cost savings resulting from increased simulation training were addressed. It was concluded that by FY79, the following reductions in flying hours could be accomplished using existing technology: UPT-50%: conversion training (combat crew)-50%. Substantial increases in the cost of fuel resulting from the Arab-Israel October War of 1973 seemed to further reinforce the increased use of flight simulators as a means of reducing costs.

In response to the suggested reductions by OMB and increased operating costs, the Office of the Secretary of Defense (OSD) set a 25% reduction in flight time as a realistic goal to be achieved by 1980. After reviewing the Air Force and Navy use of flight simulators for large, multi-engine aircraft, the General Accounting Office (GAO) in a report to the Congress, concluded that existing equipment was not being used to its full potential. The report suggested that standards be set for certifying and periodically recertifying simulator effectiveness. Furthermore, the need for proficiency flying should be re-evaluated and the possible substitution of simulator training be considered.

In view of increased procurement and operating costs for both simulators and aircraft and the trend toward increased emphasis on simulation training as a means of reducing costs, there are two pressing questions. First, how much training can be obtained from existing systems? In other words, there is a need to optimize the training received using present devices. Second, will proposed simulator modifications and hardware additions significantly enhance the training value of the device? To provide definitive answers to such questions, objective performance measurement systems are necessary. The acceptance of subjective opinion is rapidly diminishing as justification for new simulator acquisitions and modifications to existing devices. In view of the need to provide adequate documentation, the development of objective performance measurement systems is imperative.

In late 1973, the Air Force Human Resources Laboratory/Flying Training Division (AFHRL/FT) initiated consultative assistance to the Military Airlift Command (MAC). In an attempt to obtain further assistance, MAC initiated a Request for Personnel Research (RPR) in which one of the objectives concerned the application of training effectiveness measurement to the evaluation of their training programs. Although the initial RPR was not approved, these objectives were included in the Air Force Master Simulation Plan and a dialogue between AFHRL/FT and MAC continued. In May 1976, MAC initiated another RPR (76-20), entitled "Aircrew Performance Measurement System," which was subsequently validated.

The objectives of this RPR were to: (1) identify objectively the mission task requirements for MAC aircrew members through an analysis of training syllabuses, STAN/EVAL performance criteria, and flying training records when appropriate, (2) describe current and planned flight simulator and aircraft capabilities in terms of their use in generating mission performance measurement for MAC aircrew members, and (3) develop and evaluate an objective/quantitative measurement system for MAC aircrews based on the mission task requirements and the capabilities of command flight simulation systems as well as the aircraft. Through coordination between MAC and AFHRL, the C-5 was selected as the target system for research and development (R&D) efforts in response to the RPR.

Statement Of The Problem

Aircrew performance evaluation in MAC currently consists of standardization and evaluation (STAN-EVAL) checkrides in which highly qualified evaluators subjectively rate aircrew performance. While generally adequate for certifying initial qualification, these procedures may not be as effective as objective performance measures based upon predefined standards of performance for assessing transfer of training from the simulator to the aircraft. The validity and reliability of these quantitative measures are also enhanced thorough standardization and repeatablity. Hence, MAC's strong commitment to Instructional Systems Development (ISD), its endorsement of the concept of proficiency training, and the existence of state-of-the-art digital

simulators have all provided the impetus for developing a valid, reliable, and objective/quantitative performance measurement system for assessing aircrew proficiency using the C-5 simulator.

In order to achieve this goal, however, a careful analysis must be made of MAC's operational missions, doctrine, and philosophy in order to determine unique requirements that should be considered in developing a performance measurement scheme. The unique requirements for a highly complex and sophisticated multicrew aircraft, such as the C-5, must likewise be considered. For example, the requirements for crew coordination, for extensive preflight inspection and checkout of automated systems, and for procedural operations and inflight monitoring must all be considered if the performance measurement system is to have operational validity. Unless these factors are weighed and appropriately incorporated into the specification of a performance measurement system, which addresses these unique aircrew performance requirements, the ability to assess operational performance and objectively evaluate aircrew proficiency during airlift operations will be limited.

Without operational validity, as well as measurement validity, a performance measurement system will not have the capability to differentiate between differing levels of aircrew performance required to objectively assess proficiency at various stages of operational qualification. Further, it would also limit the ability to evaluate the entire crew or to make comparisons among various training and/or operational conditions. The challenge in this research effort thus becomes one of defining a candidate set of performance measures which reflects not only performance requirements within the constraints of the specific mission and weapon system for each crew position, but is also responsive to the users' needs for objectively evaluating proficiency through quantitative indices monitored and scored in the C-5 simulator at various levels of operational readiness.

In view of these considerations, the definition of the requirements for a performance measurement system for C-5 aircrew members required a four-phase effort. The objectives of each phase were:

(1) Phase I - to identify and define C-5 aircrew tasks and performance variables which are essential to the effective operation of the C-5 aircraft system in characteristic and representative MAC missions.

(2) Phase II - to describe the capabilities of current and projected new C-5 simulators and determine how their capabilities can be employed to measure crew performance on essential mission operational tasks.

(3) Phase III - to synthesize the data generated during Phases I and II to describe the requirements for a C-5 aircrew performance measurement system to be used in subsequent research efforts to guide the development and implementation of the required simulator measurement system.

(4) Phase IV – to develop a functional specification for an airborne performance measurement system for the C-5 aircraft so that equivalent simulator and aircraft measurements could be made to whatever extent possible.

SECTION II

PHASE I

The objective of Phase I was to analyze C-5 aircrew performance
requirements during military airlift operations in order to define a
candidate set of performance measures for assessing aircrew proficiency.
The data sources for this analysis consisted of operational and training
documentation; interviews with training supervisors, instructors, and
evaluators; and dialogue with operationally qualified aircrews. The
results of the analysis led to the development of a special-purpose
evaluation sortie for the C-5 simulator, which will support the objec-
tive evaluation of aircrew proficiency required for initial qualification
using quantitative performance measurement techniques and yet be general-
izable to operational evaluation as well.

APPROACH

Analysis of Aircrew Performance Requirements

The analysis of aircrew performance requirements involved three
separate but interrelated efforts: (1) determination and segmentation
of a representative mission profile, (2) determination of aircrew
activities within each segment and (3) determination of mission-essential/
critical aircrew tasks and duties from among these aircrew activities.

Determination of the Mission Profile. The determination and
segmentation of the mission profile resulted in the definition of a
representative mission. The phases into which the mission was parti-
tioned were similar to routine phases-of-flight, although expanded
somewhat to include relevant preflight and postflight activities. A
complete mission profile was constructed using these phases. The next
step was to determine typical aircrew functions within the phases. This
step involved a higher level of detail and resulted in a further parti-
tioning of the mission into segments within phases. For example, the
phase identified as takeoff/climb was further segmented into (1) line-up,
(2) takeoff, (3) initial climb and (4) departure.

At this point of analysis, the profile, including segments and events
within the segments, was reviewed by the C-5 Instructional System
Developement (ISD) team at Altus AFB. The review was to: (1) finalize
(and correct where necessary) the structure of the mission profile in
detail and (2) identify and insert the various malfunctions, conting-
encies, and deviations from the nominal flight plan. Throughout this
initial effort, heavy reliance was placed on both the operational
expertise of the ISD team and the various C-5 training and operational
documents, including the Flight Manual (dash 1) and the TASK Inventories
compiled by the C-5 ISD program.

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Determination of Aircrew Activities. The next effort in the
analysis of aircrew performance requirements was the determination of
aircrew activities within each segment. This effort started from the
previously noted functions within the mission segments and finished with
two separate but related products. The first product consisted of a
revised mission profile containing additional levels of detail added by
the C-5 operational personnel. That is, within the events, key "items"
were identified that were either mission-essential or critical; for
example, during line-up, flaps were noted to be 40 percent and the Take-
Off Landing Data card data reviewed. Task-level activities were also
noted for the various crewmembers, such as pilot/copilot gear and flap
activations after takeoff. Key checklist items were identified in their
sequential order, and a number of tentative measurement variables were
noted such as the 8 to 10 degree pitch envelope at rotation.

The development of this profile again relied on available documents
and C-5 training personnel to: (1) determine the order, sequence, and
time line of events and (2) provide additional operational details.

The second product developed in the determination of aircrew activi-
ties consisted of basic operational sequence diagrams (OSDs). These
OSDs were developed for the pilot/copilot for the entire mission from
the ISD task inventories. They were also developed for the navigator
and flight engineer for selected portions of the mission with particular
attention devoted to the interior inspection. Finally, OSDs were
developed for all crew positions involved in selected manfunctions. The
OSDs for the pilot/copilot and navigator positions were derived from the
task listings and double-checked against the Dash 1. For the flight
engineer, they were derived from the Dash 1, exclusively, and checked
by operational personnel for accuracy. The OSDs that were developed .
provided additional levels of detail for the individual crewmember
positions. Level of detail represented was that of discrete switch
actions, dials and gauges monitored, and lever/handle position settings.

Both the detailed mission profile and the OSDs were again reviewed by
C-5 aircrews at Altus for representativeness and to verify their opera-
tional validity for the determination of essential or critical crew-
member tasks and duties.

Determination of Mission-Essential/Critical Tasks and Duties. The
determination of essential and/or critical tasks and duties required a
cooperative effort between training analysts and the C-5 operational
aircrews. The effort involved was that of progressing step by step
through all the tasks and duties listed in the mission profile and
contained in the OSDs. Each essential/critical item was noted and
additional detail supplied to facilitate later decisions regarding
measurement of performance parameters. This process involved nominal
mission activities as well as malfunctions and/or contingencies.

The determination of essential and critical crewmember tasks and
duties was based upon the expertise of the operationally qualified C-5
aircrew personnel. Operationally, an essential item is characterized by

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the fact that, if omitted, the mission or segment cannot be continued or completed successfully. Thus, the referent is completeness. An example of essentiality of an item is seen in the case of omitting the power-on step in engine start. The procedure simply cannot be completed without this step. Criticality, on the other hand, refers to the impact of an item in the sense that its omission or incorrect accomplishment would jeopardize mission safety or equipment. An example of a critical omission is failure to execute a missed approach at decision height when the situation warrants it. Though these definitions are neither mutually exclusive nor systematically formalized, it is clear that both essential and critical items affect mission effectiveness and efficiency. As such, they consitute working definitions subject to the consensus of C-5 advisory personnel and training analysts and allow for reasonable progress in the task of denoting performance requirements.

Definition of Performance Measurement Requirements.

In addition to aircrew performance requirements, there is another set of requirements relating to performance measurement, per se, which must be considered. These requirements are concerned with the nature of the measurement process, the characteristics of the performance data, and the scheme for collecting these data.

As previously indicated, the fundamental nature of the performance measurement system should be valid and reliable. That is, for validity, the performance measures themselves should be directly related to the underlying skills and proficiencies required for operational qualification and the criterion for evaluating proficiency should be derived from the skills analysis. Reliability, on the other hand, simply means that measures selected should reflect sufficient stability and precision to consistently discriminate between different levels of performance upon repeated measures, again a reflection of the basic nature of the criterion. Besides these two essential characteristics, the performance measures should be objective and quantitative as well: objective in the sense that they are observable and verifiable, with well-defined conditions and standards and tolerances are stated in units that will enable both absolute and comparative evaluations of performance to be made.

In addition to these salient properties of a measurement system, certain data characteristics were also examined for their implications. For example, the analysis of the aircrew performance requirements indicated that the vast majority of the crew activities consisted of complex motor skills that can be classified as either continuous or discrete tasks. In the case of the continuous tasks, such as maintaining various flight parameters within prescribed tolerance limits, the appropriate measures have usually been found to be error or deviation scores intergrated over some predefined time interval; e.g., RMS or mean error scores. Discrete tasks, such as switch settings in checklist or procedural items, represent state monitoring as a measurement technique in which switch positions can be checked at selected times or during some prespecified interval where precise timing is crucial. Another form of discrete task examined was data entry of airborne computers in which

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digital inputs can be monitored and compared to predetermined values for format and accuracy. These types of data characteristics, which are unique to operator performance, all impact the general requirements for performance measurement.

A final set of considerations involves the collection and sampling of data for performance measurement. Such issues as sampling rates and intervals, as well as the representativeness of the sampled data, were examined. That is, the data measures should be a cross-section of the skills required for each crew position throughout the entire mission profile. The frequency, duration, and density of the measure in all segments of flight should also be balanced in order to avoid biasing due to the effects of workload and/or fatigue. Sampling for measurement effectiveness and efficiency is also a consideration. For example, in order to avoid conflicts in terms of processing, the data relating two different crewmembers performing different tasks during the same time period may require various priorities to be established. In addition, the entire measurement set should consist of as few measures as possible which will yield indications of the adequacy of performance. That is, there are frequently several measures of the same skill which could be taken simultaneously but analysis of the performance requirements often will indicate which should be selected, e.g., heading vs. track or air-speed vs. groundspeed.

In general, the eventual impact of these requirements upon a performance measurement system cannot be determined a priori, but rather must also depend on the configuration of the system hardware and software as well as the range of applications to be made of the system. At a preliminary level, however, these requirements have been defined with sufficient latitude and flexibility to enable a typical mission profile to be defined and candidate measures to be selected. This will provide a basis for direct application to performance evaluation for initial aircrew qualification and yet have generalization to the assessment of operational proficiency in the field.

RESULTS

Development of Evaluation Mission Profile

As a result of the analysis, it was determined that the most effective means of identifying the performance measurement candidates would be to develop a special-purpose evaluation sortie. Thus, a C-5 simulator evaluation mission profile was constructed which was representative of a typical MAC airlift mission. Through interview and discussion with MAC training personnel, review of C-5 training documents, and study of the C-5 Flight Manual, the representative mission segments were determined. The mission profile consists of segments appropriate to, and in sequence of, an operational MAC mission and was constructed on a mission time line. It was designed to contain operational activities required of the various crewmembers while performing their inflight duties during a typical mission. The mission also included contingencies and emergency situations which require crew coordination among various aircrew members and which are typical of operational mission malfunction/emergencies.

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This simulator evaluation mission was designed as a stand-alone sortie approximating an operational mission in which evaluation rather than instruction was the primary concern. The main objective was to design a mission profile consisting of segments which would require each aircrew member to perform the essential tasks and duties required on a representative airlift mission. A further objective was to provide a basis for identifying and defining candidate measurement segments from which objective evaluations could be made of an aircrew's performance proficiency. Although the emphasis was on evaluation of initial qualification requirements, the profile and measurement techniques would be sufficient for application to operational evaluations as well.

The sortie route was designed to cover a wide range of conditions and events which an aircrew might encounter on a typical operational mission and which would provide an adequate basis for skills evaluation. The activities or performance segments require widely differing tasks for each crewmember at varying times during the mission. Various mission segments are differentially weighted in terms of the type and amount of crew activity required. For example, the pilots are heavily involved during departure and arrival, with very little navigator activity, whereas the reverse is the case during the cruise segment. An attempt was made to select a profile which balances the activity across crewmembers throughout the entire profile.

The route of the evaluation mission was designed to include mission segments which provide essential and representative performance requirements for the various crewmembers. The flight plan for the mission calls for a departure from Dover AFB, with enroute navigation to San Juan VOR for a landing at Roosevelt Roads, PR.

The mission to be flown in the simulator will include the standard instrument departure (SID) with a deviation around severe weather. The flight will then proceed on the planned route to a point north of Clark, where a hydraulic system failure will occur. This emergency will necessitate a change of route and refueling for a divert to Charleston AFB. The new route will be to Charleston for an approach. A missed approach, and radar vectoring for an Instrument Landing System (ILS) to a full stop landing will complete the evaluation sortie.

Construction of the evaluation mission profile and route was accomplished to provide representative sample activities for all crewmembers. This particular sortie includes pilot and copilot inflight activities associated with the takeoff SID, climb, level off and cruise, enroute descent, VOR approach, ILS approach, and landing. The overwater route was selected to assess navigator activities associated with the various navigation modes, both inflight and on the ground. The flight engineer activities consist of emergency and malfunction situations which occur at various points throughout the mission, as well as extensive preflight checks and inflight monitoring.

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The critical checklist items and procedural activities of the crewmembers, both on the ground and when airborne, are specified at the appropriate points of the profile throughout the evaluation mission. The selection of these essential/critical tasks serves as a basis for identifying and defining candidate measures for each crew position. These measures will be associated with specific parameters, tolerances and/or steady-state conditions, which can be monitored and assessed as a means of objectively evaluating performance. A summary outline of the mission profile is presented in Table 1, along with related segments, events, crew activities, parameters, etc.

Selection of Candidate Performance Measures.

The process used in the selection of candidate measures of performance for each crew position began with the evaluation mission profile and the identified aircrew activities of each segment. Given this baseline as a starting point, the training analysts, in collaboration with qualified C-5 crewmembers, identified and defined specific crew tasks which would meet criteria of essentiality and/or criticality. In addition, tasks meeting the requirements for valid and reliable objective performance measures were identified.

The process began with a review of the entire profile for each crew position. The dash 1, checklists, and procedures, as well as the OSDs, were examined step by step for each mission segment. In addition to identifying specific crew tasks and performance segments which met these criteria and requirements, there was an effort to define a manageable subset of these activities which could be used for an efficient and effective performance evaluation.

The technique involved answering such questions as: Can selected items be identified which will allow inferences to be made concerning other items in a sequence; i.e., does the completion of the final item in a checklist mean that all other items have been completed, or are there key items within the list which would indicate that the task has been successfully completed? This type of questioning was used to limit the measurement of procedural skills, where possible, to a selected set of discrete tasks which would indicate successful performance of the procedure.

In addition, specific continuous performance segments were defined in which selected flight parameters could be identified and performance tolerances specified. During these segments, specific start and stop points were defined, as were transition zones. Evaluating performance in terms of deviations form quantitative standards, particularly during departures and arrivals, will serve as a major measure of pilot/copilot proficiency during these segments.

Other areas representing significant performance requirements as candidate measures were the data entry and system configuration tasks. In these cases, specific digital inputs can be observed, based upon pre-

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flight planning data, and switch settings can be monitored for nominal operations as a means of evaluating many navigator and flight engineer duties.

A detailed list of all the candidate measures, their conditions, and standards resulting from the foregoing selection processes are presented in Apependix A, by crew position and profile segment as outlined in Table 1.

TABLE 1. EVALUATION MISSION PROFILE SUMMARY.

Time	Phase / Segment / Event	Crew Activity[a]			Sample Measurement Activities	
		Pilot/Copilot	Navigator	Engineer	Continuous	Discrete
	I PREFLIGHT AND STARTING					
-75	Interior Inspection	–	I.B.1(1)	I.C.1(1)	–	Navigator inputs
-30	Before Starting Engines	I.A.1[b](1)[a]	–	–	–	Pilot/copilot procedures
-20	Starting Engines	I.A.2(1)	–	–	–	–
	Starter Button Fails	I.A.2(2)	–	(3)	–	Corrective actions
	II TAXI AND BEFORE TAKEOFF					
-10	Before Taxi	II.A.1(1)	II.B.1(1)	II.C.1(1)	–	Checklist items
	Taxi	II.A.2(2)	–	–	–	Corrective action
	Caster malfunction	(3)	–	–	–	Corrective action
	Takeoff Data	Update	–	–	–	–
-5	Before Takeoff	II.A.3(1)	II.B.2(1)	II.C.2(1)	–	Set flaps
	Set Disconnect	–	–	–	–	Cycle flaps
	III TAKEOFF/CLIMB					
	Lineup	III.A.1(1)	–	–	–	Set for takeoff
	Takeoff	III.A.2(2)	(3)	–	Rotation airspeed	Altitude
	Initial Climb	III.A.3(2)	(3)	III.C.1(1)	Airspeed	Landing gear
0	Landing gear failure	III.A.3(2)	–	–	–	Crosswind reset
	Departure	(2)	(3)	–	Airspeed, track	–
	SID	III.A.4(2)	(3)	–	Airspeed, track, altitude	Altimeter setting
	Pressurization failure	–	–	III.C.2(2)	–	Corrective action
	Weather deviation	(2)	(3)	–	–	–
	IV ENROUTE					
+20	Level Off	IV.A.1(2)	IV.B.1(2)	–	Altitude	Autopilot engage
	Cruise	(2)	IV.B.2(2)	–	Position, altitude, airspeed	IDNE fix

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TABLE 1. EVALUATION MISSION PROFILE SUMMARY. (Cont)

Time	Phase Segment Event	Crew Activity[a] Pilot/Copilot	Navigator	Engineer	Sample Measurement Activities Continuous	Discrete
	Vibration Check	--	--	IV.C.1(3)	--	Engine analysis
	Hydraulic Failure	--	--	IV.C.2(3)	--	--
	Generator Failure	--	--	IV.C.3(3)	--	Corrective action
▼ DESCENT/APPROACH/LANDING						
1 + 20	Enroute Descent	V.A.1(1)(3)	V.B.1(1)	V.C.1(1)	Vertical navigation	Navigator inputs
1 + 41	Holding	V.A.2(3)	V.B.2(3)	(3)	Altitude, airspeed	Altimeter set
1 + 55	Low Altitude Approach V.3	V.A.3(3)	(3)	(3)	--	--
	IAP	V.A.3(1)(3)	(3)	(3)	Position, altitude, heading	Gear, flaps
	Arc	V.A.3(3)	(3)	(3)	Position, airspeed, altitude	--
	Final Approach	V.A.3(3)	(3)	(3)	Track, airspeed, altitude	Flaps
	Missed Approach	V.A.4(3)	(3)	(3)	Altitude	--
2 + 10	ILS	(1)	(3)	(3)	Azimuth, glide slope, airspeed	--
2 + 30	After Landing	--	V.B.3(1)	V.C.2(1)	--	--
	Engine Shutdown		(3)	(1)	--	--

NOTES

a. Crew activities are designated as follows:

(1) Indicates checklist items.

(2) Indicates procedural items.

(3) Indicates monitoring of events.

b. Numeral/letter identifier of the appendix paragraph which lists the specific crew activities to be measured.

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SECTION III

PHASE II

The objective of Phase II was to describe current and/or projected capabilities required to measure crew performance on mission-essential operational tasks during representative airlift sorties. The goal was to determine how the existing C-5 simulator could be augemented to provide quantitative performance measurement for evaluating aircrew proficiency. The methods used to accomplish this consisted of an examination of the existing system and a review of the technical documentation, as well as extensive dialogue with the training device technicians by the contractor's system engineers. The results of these efforts led to the definition of several alternative configurations for modifying the present system so that it will: (1) meet the performance measurement requirements identified in Phase I and (2) provide MAC with the capabilities of conducting objective aircrew performance evaluations.

APPROACH

Review of Performance Measurement Requirements.

The initial effort of Phase II consisted of a review of the performance measurement requirements which had been identified and defined during Phase I. As previously indicated, these requirements served as a baseline for examining the existing C-5 simulator system in terms of objective performance measurement capabilities. These requirements had established the types of aircrew activities performed during a nominal airlift mission and determined the nature of the performance measures that would be appropriate for assessing aircrew proficiency. The essential characteristics of the performance measurement scheme had also been specified. These requirements provided the system engineers an indication of the kinds of measurement capabilities which would be required to conduct objective performance evaluation and served as a basis for their examination of the existing system.

The candidate measures identified for each crew position, during specific segments of a nominal mission profile, consisted of both discrete and continuous tasks. The data indicated not only the type of tasks but the specific system components involved, as well as the performance conditions and standards to be met. Systems engineers, reviewing this information, could then determine the data sources, formats, and rates required for extraction and the specific data locations to be examined. The identification of crew activities, by segment, against a nominal time line also indicated the general timing requirements as well as an assessment of the data processing rates and loads to be considered. In the case of continuous measures, the flight parameters identified and the prespecified tolerances indicated the type of data transformations and/or

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manipulations required. The particular start and stop points for these measures were also specified, indicating to the systems engineers the amount of data to be handled.

In addition to data requirements, the Phase I results also gave engineers an indication of other general functional capabilities required to support objective performance evaluation. Such features as problem control (e.g., initialization and malfunction insertion) and instructor aiding (e.g., data prints/plots and performance scoring) were indicated by the nature of the mission profile and contingencies. The capability of the existing system to provide these support functions was also considered in the preliminary examination of the C-5 simulator.

From this initial baseline of performance measurement requirements and supporting functions, the systems engineers could proceed with a systematic analysis and assessment of the capabilities of the existing system. The results of this effort were to provide a description of the present capabilities and limitations for conducting objective performance measurement and to suggest alternatives for augmenting the current system to meet these requirements.

Analysis of Performance Measurement Capabilities.

The analysis of performance measurement capabilities of the existing C-5 simulator was conducted by systems engineers with considerable background and experience in simulation technology. The basic approach involved an on-site visit to the simulation facility at Altus AFB and a comprehensive examination of the technical documentation. During a period of 4 days, a systems engineer studied the operator's manual, the simulator manufacturer's technical manuals, the computational system documentation, and other related publications. With the cooperation of a senior training device technician, the schematic and wiring diagrams were reviewed and configuration and/or modification documentation was examined. The technician was questioned concerning both hardware and software features and operational characteristics. During this period, a general impression of the system capabilities and limitations was established and sufficient information was gathered concerning the present configuration to develop a description of the current potential for conducting performance measurement.

The systems engineer examined the architecture of the computational system and established the storage, processing, and timing capacities for the C-5 simulator in order to determine the reserve capabilities that could be used for performance measurement. The documentation and the systems operations were studied to establish how to most effectively interface with existing components in the event system augmentation was required. A review was made of the present facilities for inputting and outputting data, and the existing capabilities for monitoring and processing the types of data identified in Phase I were assessed. An examination was made of the available peripheral devices and the software capabilities to determine the feasibility for modification to meet the requirements for performance measurement.

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The engineering analysis also investigated the potential capability for providing the supporting functions of performance measurement. This included the inherent capabilities to specify and control variables, to extract and display performance data, and the ability or degree of instructor intervention and real-time control over the scenario and/or events.

This analysis, performed in light of the performance measurement requirements established in Phase I, allowed the formulation of a description of the measurement capabilities of the present C-5 simulation system and the identification of the basic limitations for conducting objective performance measurement given the existing system design. It also provided the basis for the development of several alternative system configurations which could be added to the basic C-5 system complex to provide the capabilities for meeting the performance measurement requirements.

RESULTS

Description of Current Measurement Capabilities.

The current measurement capabilities of the C-5 simulator were assessed in terms of the ability to monitor and process the types of performance data identified as candidate measures in Phase I. A description of the system's current configuration and the computational system resources required to support a performance measurement system (PMS) is presented, along with a brief discussion of modifications which could be made to the existing processors to accommodate limited measurement capabilities.

The simulator flight deck contains the four trainee positions (pilot, copilot, navigator, and flight engineer) in addition to three instructor positions: instructor pilot, instructor navigator, and flight engineer instructor. The instructors rely primarily on the aircraft instrumentation at the trainee positions for mission monitoring; therefore, any performance assessment is accomplished by the instructor through over-the-shoulder observations. Additionally, each instructor has parameter insertion facilities which are used primarily for malfunction insertions. The pilot instructor and the navigator instructor positions are provided with closed circuit television montiors (CCTVs) which allow each instructor to select either mission plot or malfunction status displays.

The radio aids station, adjacent to the simulator flight deck, provides the facilities for initial problem setup, control of radar targets, and radar jamming, as well as onboard and external communications simulation. The general layout of the simulator and the major components are shown in Figure 1.
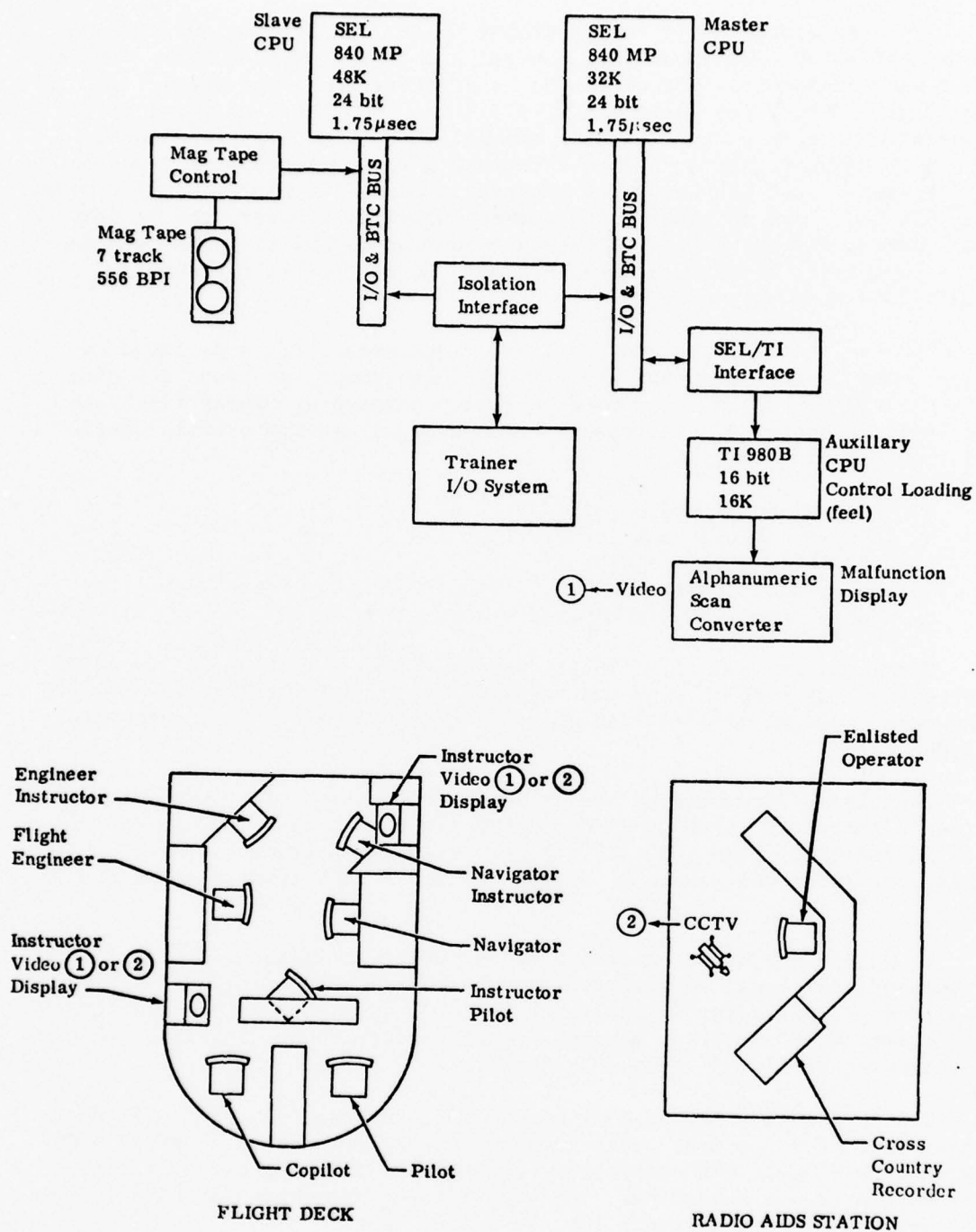
Figure 1.   Existing C-5 Trainer.

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The simulator's basic computational system consists of two Systems Engineering Lab (SEL) Model 840 central processing units (CPUs). These CPUs were designed in the mid-1960s as discrete component items. An auxiliary CUP, Texas Instruments (TI) Model 980B has been added to the system to perform control loading and malfunction display functions. The SEL computers time-share an interface port to the trainer input/our (I/O) system, and the interface operates in a 24-bit block transfer mode. The SEL 840s have no excess programming capacity; however, the TI 980B does have a limited amount of excess computing capability plus an expansion capability in terms of memory size. No on-line file access capability presently exists.

The estimates of the computational requirements for a performance measurement system are based on various measurement functions and data characteristics of the candidate performance measure. These functions and their associated requirements for a nominal mission profile consist of the following elements:

    a. Logical decisions - 1075.
    b. Analog calculations -·300.
    c. Potential errors - 465.
    d. Measurement tasks - 117.
    e. Mementary signals monitored - 138.

Using the formula size (16-bit words) = 8(a) + 14(b) + 5(c) + 40(d) for estimating program size and assuming that a straightforward assembly language could be used for coding, the estimated core requirements are 21,065 cells.

The timing requirements are primarily a function of the momentary signals monitored (element e) and are estimated to be 10,000 instructions per second (IPS) plus 5000 IPS for performance measurement system logic. This represents only about 3 percent of the TI 980B instruction execution rate.

If an on-line error reporting requirement was imposed, a significant amount of additional message storage and formatting logic would be required. This factor is estimated to be 30 bytes of text and 10 words of format logic per error message. This results in an additional memory requirement of 11,625 cells (25 x 465).

The performance measurement system software can then be typified as requiring access to many small measurement tasks, each task having many logical branches. The completion requirements in terms of instructions per second is not demanding. The single most challenging problem is how to report and catalog errors for the system user.

Because of the nature of the performance measurement system computation problem (considerable logic and little CPU execution time), it is recommended that the performance measurement system be developed in a high level programming language (probably FORTRAN). Use of a high level

language not only reduces initial programming cost, but greatly enhances the flexibility of the system for changes in the field.

The only feasible configuration of the performance measurement system which uses existing CPU capacity consists of upgrading the TI 980B to a disk operating system environment capable of foreground/background operations. The foreground operation would be the existing control loading task. The performance measurement system would be operated out of the background. In this environment, the performance measurement system executive routine would swap in logic from the disk depending on the phase of the mission.

The TI 980B could be equipped with 32K of memory, allocated as follows:

    3K - Trainer I/O variables
    4K - Performance measurement system executive and common
         subroutines
    5K - Math and display formatting routines
    5K - Performance measurement system swap area
    2K - Foreground/background executive
    7K - Foreground task (control loading)
    6K - Disk operating system
    ───
    32K

The total amount of performance measurement system related logic would be approximately 48K when coded in high level as opposed to about 31K in assembly language. The bulk of the performance measurement system logic (40K) would be stored on disk and loaded only as needed.

In the current configuration, the TI 980B performs the vital control loading (feel) task for the simulator. Software bugs in the performance measurement system would likely interfere with or stop basic simulation. Use of the TI 980B for off-line performance measurement system related tasks (program modification, examining run statistics, etc) would similarly risk training operations. The solution to this problem is to spend extra money in software to minimize the risk or to simply not allow any off-line activity on the TI 980B except during non-training and non-maintenance hours.

Adding the performance measurement system function to the TI 980B would require adding software to the basic simulation computers (SEL 840s) to supply trainer state data to the performance measurement system routines. The executive software for the TI 980 would have to be totally rewritten. Only those routines associated with the control loading function would be retained. A foreground/background executive would have to be developed. In light of these constraints, the technical feasibility and cost-effectiveness of such an approach does not appear to be viable.

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TABLE 2. C-5/F-4E TRAINER-TO-COMPUTER INTERFACE COMPARISON

Characteristic	C-5		F-4E WSTS	
Word size	24 bits		24 bits	
Number of	D/A	512	D/A	384
trainer I/O	A/D	192	A/D	128
channels	DSI	112	DSI	82
	DSO/DWO	96	DSO/DWO	90
	Total	912	Total	684
Transfer rate (burst)	285 K wd/sec		750 K wd/sec	
Interfacing circuitry	+12V logic levels		MCEL differential	

Definition of Alternative System Configurations.

As indicated, the current C-5 simulator configuration presently provides limited capabilities for accomplishing performance measurement. Therefore, it appears that the more feasible and cost-effective approach would involve the augmentation of the existing system by means of an independent and autonomous strap-on system which would ride "piggy-back" on the basic simulation system. Such a system, totally transparent to the existing trainer, centers around the use of a minicomputer.

This approach also requires the development of a trainer interface (data acquisition unit) which allows the system to capture any or all information that is provided in the trainer. The design for such a system requires that it be totally invisible to the basic system CPUs, i.e., no programming changes to trainer software.

It is recommended that a similar approach be used for the C-5 trainer. In fact, the design for the interface unit similar to that used on the F-4E Weapons System Trainer, which incorporates a Data Acquisition and Control Unit (DACU), is readily adaptable to the C-5 trainer. Table 2 shows a comparison of the characteristics of the trainer-to-computer interface on these two systems.

The C-5 requirements are well within the throughput capability of the DACU design. The DACU in its current configuration provides the capacity for monitoring and control of as many as 2000 trainer I/O channels. The F-4E I/O rate exceeds that required for the C-5. The trainer interface section of the DACU would require modification to adapt to the difference in control signals and interface circuit characteristics.

Within this general framework, five alternative configurations were examined which varied in the range of capabilities and support functions that would be provided. The hardware and software components for each configuration were specified and the associated costs estimated. In general, they represented a range of lesser to greater capability, lesser to greater flexibility, and lesser to greater utility. The first configuration represented a modification and use of existing equipment while the other four utilized an "add-on" approach. All were defined in terms of functional capabilities and specified in terms of their hardware/software components. They were hierarchically arranged from the simple to the complex in order to make their similarities and differences apparent and were presented as performance measurement system candidates for further consideration in Phase III of this project. These configurations and their associated capabilities are summarized in Table 3.

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TABLE 3. CONFIGURATION/CAPABILITY MATRIX

Capabilities	Configurations				
	A	B	C	D	E
Performance measurement	X	X	X	X	X
Debriefing report	X	X	X	X	X
PMS data collection	X	X	X	X	X
PMS data analysis		X	X	X	X
Instructor displays:					
Mission sequence	X	X	X	X	X
Task measurement		X	X	X	X
Error alert		X	X	X	X
Checklist display				X	X
Route chart				X	X
Mission plot			X	X	X
Remote monitoring					X
Problem control				X	X

SECTION IV

PHASE III

The basic objective of Phase III was to describe the functional and engineering requirements for a C-5 performance measurement system. The development and implementation of such a system would not only provide the capability to objectively and quantitatively evaluate C-5 aircrew performance in both initial and continuation training regimes, but would also support future research efforts in such areas as objective assessment of crew management functions and the eventual development of an effective and efficient inflight performance measurement system.

APPROACH

Systems Requirements.

The C-5 performance measurement system must satisfy or exceed performance measurement requirements at both the specific and the general levels of utility. At the specific level are the requirements for measuring well-defined mission performances of aircrew members, both individually and as an integrated crew. At this level, the performances to be measured are specified in terms of their conditions and standards, time of occurrence, specific crewmembers involved, essentially, criticality, and so forth.

At the general, or global level, the basic nature of the performance measurement system is of interest. This includes flexibility and adaptability of the system, problem control and instructor intervention capabilities of the system, data display and formatting capabilities of the system, growth potential, and others. It also includes capabilities for getting at special or unique performances, which constitute inportant but hard to define mission requirements, such as crew management and/or effective and efficient crew coordination.

These required capabilities must be provided within the specific context of the C-5 flight simulation environment. Whereas the primary focus of the performance measurement system is that of performance measurement and evaluation, that of the C-5 flight simulation is training. Thus, the capabilities required of the PMS must be provided without interruption to or interference with ongoing simulation training. At the same time, the potential for enhancing the training itself must not be overlooked.

Problem control and instructor intervention capabilities refer to the general conduct of the mission with regard to the specific activities which are planned or programmed into the evaluation/training mission profile. Though problem control is a primary instructor responsibility,

the ways and means of its implementation vary widely. These range from direct instructor intervention to the scenario through full automation and preprogramming of scenario contingencies. Clearly the ways and means of problem control directly impact the requirements of the performance measurement system. One extreme is represented by direct intervention of the instructor on a purely discretionary basis, usually resulting in nonstandardized, highly variable instructional techniques. Objective/quantitative performance measurement capabilities under this condition must be as variable and nonstandard as the instructional techniques themselves. The other extreme is represented by fully automated pre-programmed scenarios which include the performance measurement capabilities as an integral part of the complete package. In this case, both scenario control and performance measurement are systematically derived in complementary fashion from the start. The advantages of this latter approach include:

a. Standardized performance measurement across the entire student spectrum - Though individual differences in student proficiencies will persist, minimum standards of acceptability are well-defined and automatically adhered to.

b. Reduction of the instructor's workload - In effect, the instructor's time can be spent in providing instruction and guidance to the students rather than in performance measurement, assessment, and evaluation.

c. Objectivity/quantifiability/conformity of the performance measures - An automated performance measurement system lends itself most readily to these characteristics. Since not all the automated measures will be objective/quantitative in the strictest sense of the word, they must all be screened in terms of conformity or agreement by subject matter experts prior to establishment in the system.

Data display and formatting considerations are those of providing performance measurement data to the instructors, students, and evaluation personnel in the most useful manner possible within the limitations of the system. Such considerations as the need for hardcopy printout, CRT display, immediate feedback, and statistical analyses must be assessed. Other considerations are associated with the need for permanent records, filing and storage capabilities, etc. Also to be considered is the fact that instructors, students, and evaluation personnel each have different uses for the data presented, in spite of the fact that much of the time these personnel will be looking at the same data.

These considerations were of primary concern in the determination of the type of system required. To provide the wide range of capabilities within the specific environment of C-5 simulation training requires a strap-on, non-interference system with the capabilities for augmentation of training as well as those of performance measurement and evaluation.

The performance measurement system becomes a true accessory system, because when it is turned off the host system functions as it did prior to the installation of the performance measurement system.

With the performance measurement system turned on, the host system continues to provide all of its previous capabilities, but with augmentation of some of these capabilities to specifically provide performance measurement and eveluation.

Data Acquisition and Control Requirements.

Functionally, the data acquisition and control requirements are determined by the baseline or representative mission developed in Phase I. That is, each of the essential/critical performance items identified in that mission is considered to be a candidate performance measure. Thus, the digital data associated with each of these candidate measures are, in turn, candidate data for processing by the performance measurement system.

The data acquisition and control characteristics provided to accommodate the representative mission represent general capabilities. For this reason, the data from a wide range of missions, in addition to the representative mission, can be acquired and processed both to enhance training and to evaluate proficiency at various performance levels. Important in this respect are the following system data capabilities:

a. Capability to acquire any instrument reading, control setting, switch position, etc.

b. Capability to automate any of the instructional feature functions presently available on the simulator. This capability includes both the functions which are presently automated as well as those which require manual entry.

The integration of these capabilities in the specified performance measurement system should provide for a complete "hands-off" operation on demand which would automatically and simultaneously (1) present the total mission scenario to the student and (2) assess and evaluate all mission-essential/critical performance items in the scenario. The system should, in addition, provide hardcopy printouts of performance data which are responsive to prespecified portions of the mission, as well as to different user requirements.

Selection of Configuration.

At the conclusion of Phase II of the project, five alternative performance measurement system configurations were presented for review and subsequent selection of the most viable alternative. The most salient feature of these configurations were as follows:

a. Configuration A consisted primarily of a data collection plan based upon utilization of the existing C-5 simulator capabilities.

b. Configuration B consisted of a separate minicomputer for data collection and processing coupled with alphanumeric capabilities for limited display.

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c. Configuration C included capabilities noted above for configuration A and B and, in addition, included graphic capabilities for display along with alphanumerics.

d. Configuration D included the above capabilities combined in a multimedia display and, in addition, significant capabilities for scenario (mission profile) control.

e. Configuration E included the above with different location of the instructor/evaluator stations. (Whereas configuration D included these stations on the simulator flight deck, E located them remotely from the flight deck). Configurations A and B provided strictly monitoring capabilities and required prompting and/or initiation of the function itself by the instructor.

At the conclusion of the review period, configuration D was selected for further consideration for development as an experimental prototype version. The selection rationale can be seen from the brief, general-level descriptions provided above. The first three configurations provided limited performance evaluation/assessment capabilities at the expense of additional effort on the part of the instructor/evaluator. Configuration D provided a blend of multimedia display capabilities and a range of options for instructor control of the mission scenario. These options include both automation and direct instructor intervention to the scenario. Configuration E duplicated the capabilities of D with the exception that E located the instructor stations remotely from the flight deck.

Specifically, configuration D can acquire any instrument reading, control setting, switch position, etc. that is available on the simulator. Any of these may be automatically or manually monitored, acquired, and/or otherwise processed for performance evaluation and assessment. In addition, aircraft geographic position may be established at any instructor station. This capability is derived by combining display capabilities with acquisition and plotting capabilities. Aircraft position may be acquired within $\pm$10 feet each 0.8 second or less. This position or track may be displayed with respect to the geographic charts appropriate to the mission.

Instructor intervention to the evaluation mission scenario can be either automatic or manual. The entire scenaio can be preprogrammed before the mission is conducted. In addition, manual instructor intervention capabilities are provided for the on-line insertion of malfunctions and mission contingencies, such as weather and/or diversion to alternate landing sites, etc. These manual entry capabilities are in addition to the automatic means provided for malfunction/contigency presentation to the student.

Configuration D also provides the capabilities for both independent assessment of individual crewmembers' performance and the assessment of aircrew (crew-coordinated) performance. Thus, the potential is provided for the evaluation of a broad scale of performance measurement possibilities, ranging from the treatment of individual crewmember proficiency up through crew-coordination and crew management skills.

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RESULTS

Functional/Engineering Specifications for C-5 Performance Measurement System

Considerations noted above led to the conceptualization of a C-5 performance measurement system which has the following capabilities.

Flexible and Adaptable Measures of Student Proficiency

Flexibility and adaptability of the measurement system refer to (1) the range of performance variability over which the measures retain their validity and reliability and (2) the range over which the measurement requirements themselves may vary without exceeding the limits of the performance measurement system. The first of these two considerations is with respect to possible variations in student proficiency levels. Presently, C-5 students have previously qualified in C-141. Thus, their entry level proficiency is quite advanced; the training and measurement requirements are those associated with transition. Should this entry level of proficiency change to a less advanced state, the performance measurement system must hopefully be flexible enough to accommodate the change. In any event, the range of performance variability the system is able to accommodate must be well defined.

The second of these two considerations is with respect to variations in the measurement requirements themselves. Such changes could stem from several sources, including:

a. Changes to the basic mission profile such as the recent addition of air refueling.

b. Changes to either nominal or emergency procedures, based on experience or safety.

c. Changes to procedures based on possible equipment/configuration changes to the aircraft.

Any of these changes would be reflected from the mission itself back to the training program and would thus significantly impact the performance measurement system. For this reason, the range over which the measurement requirements may vary without exceeding the limits of the performance measurement system must be well defined, with due attention given to likely or expected changes.

Problem Control and Instructor Intervention Capabilities.

Problem control and instructor intervention capabilities of the system are of two primary types. The primary means of control is available at a programming/maintenance terminal located off the flight deck. At this terminal, capabilities shall be provided for preprogramming the entire mission scenario, including all malfunctions and mission contingencies. Hydraulic and electrical failures can be included as can weather and diversions to alternate destinations. These capabilities are provided without any adverse impact upon the operation of the simulator itself.

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Instructor intervention capabilities shall be provided at the flight deck instructor station. These shall consist of the capability for calling up any of the route charts, approach and departure plates, etc. They shall also include call-up capability for any of the checklists, emergency procedures, etc. which are provided as a part of the total mission scenario. These capabilities shall exist in addition to the preprogramming capabilities noted above. The primary function of the flight deck capabilities is to furnish a means for the instructor/evaluator to have a closer or more detailed look at some aspect of the scenario from the perspective of his own crew position responsibilities. Similarly, relevant information shall be included for the insturctor navigator. Among the items to be included at this station would be navigation charts, navigator-specific checklists, etc.

The greater part of the flight engineer's duties occur prior to takeoff. Performance of these duties requires his moving around the aircraft rather than remaining at his own duty station. His preflight responsibilities are particularly concentrated in the pliot/copilot stations where he is responsible for readying both cockits for use. Once airborne, critical flight engineer duties continue to require his moving around to various locations aboard the aircraft. These factors, coupled with severe space limitations at the flight engineer instructor station, led to the decision to have the flight engineer share the display console with the instructor rather than to provide a separate console. As noted above, items critical to flight engineer performance evaluation shall be provided at the pilot console until the point at which the instructor takes command of the station. These items shall be provided on a call-up basis and shall include checklist and procedural items by means of which student performance can be evaluated.

Problem Control. For purposes of measuring and evaluating performance, problem control has a specific definition. It does not reduce or diminish presently available capabilities of the instructor to regulate events or to insert malfunctions and/or other mission contingencies. Rather, problem control capabilities provide a means by which all these factors may be preprogrammed and used on a standarized or repeatable basis. For example, a generator failure can be preprogrammed to occur at a specific point in the evaluation mission. Simultaneously, the system itself is told, via the same preprogrammed means, that the malfunction will occur, when it will occur, and what performance data must be collected on the specific malfunction. Thus, not only is the malfunction inserted automatically, the system is also automatically placed in a state of readiness for that particular malfunction. Appropriate performance measures are routinely collected and displayed/analyzed according to plan.

Instructor Intervention. Instructor intervention capabilities consist of two basic subsets of capabilities: (1) those capabilities presently available on the C-5 simulator, including malfunction insertion, etc., which the instructor can implement on-line for his own purposes and (2) additional capabilities provided at the instructor station by the performance measurement system itself. These include the capabilities for calling up route charts, approach/departure plates, checklist,

etc. These capabilities are separate and distinct from problem control capabilities, though they both may serve the ultimate purpose of performance evaluation. Whereas performance evaluation via the problem control methods noted above yields performance measures which are predefined and objective/quantitative, instructor intervention yields measures which are subjective.

This is because the evaluation of student performance is conducted by the instructor/evaluator strictly by means of over-the-shoulder observation. In the typical case, the observer relies on his operational experience to reach a judgement on student performance rather than on predefined objective measures.

The fact that these measures are subjective, however, does not deny their importance to the evaluation of student proficiency. For this reason, the performance measurement system retains both the problem control and instructor intervention capabilities.

The system-operational impact of these capabilities is as follows:

a. With the performance measurement system turned off, as noted earlier, the flight simulator will function exactly as it would without the system installed.

b. With the performance measurement system turned on, the instructor/ evaluator has two optional modes of operation.

(1) Preprogrammed mode - in which mission profile (problem) control is sequenced by the performance measurement system. All malfunctions and contingencies are inserted and evaluated automatically, providing for hands-off operation of the performance evaluation sortie.

(2) Manual control mode - in which the instructor is able to call upon his own display information which is specific to his student. Such specific information includes route charts, checklists, and other graphic/alphanumeric information.

These two capabilities may be provided separately or integrated; that is, they are both simultaneously available.

Data Display and Formatting Capabilities. Data display and formatting occur both at the flight deck instructor control and at the programming/ maintenance terminal. These capabilities differ in the following ways:

a. Flight deck - Display and formatting requirements for the flight deck controls consist of image retrieval, graphic/plot capabilities, and alphanumeric capabilities. No hardcopy printout or quantitative scoring techniques are required at flight deck stations. Image retrieval capabilities provide all necessary route charts, checklists, and other procedural items associated with ongoing student performance. Graphic/plot capabilities are those associated with airway or corridor boundaries, up-to-date plot of aircraft track, etc. Alphanumeric

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capabilities at this station provide additional commentary on the on-going display; for example, the notation of aircraft airspeed or altitude or the notation that some item on a particular checklist has been omitted.

b. Programming/maintenance terminal - Display and formatting require-ments for the programming/maintenance terminal include graphic/plot and alphanumeric capabilities in addition to provisions for hardcopy print-out of performance data. These requirements shall be provided by display terminal with hardcopy capabilities. If hardcopy capabilities are to be provided by another device, such as a teletypewriter, it must be capable of character output of 60 characters/second or greater. Image retrieval capabilities, as such, shall not be required at this station; however, graphic/plot capabilities must be capable of providing limited information such as aircraft track and corridor boundaries.

Due primarily to space limitations on the flight deck, data display and formatting capabilities must be contained in a package of limited size. Space cannot be provided for standard CRT or hardcopy equipment, though these items may be provided at the programming/maintenance terminal.

Hardware/Software Requirements for C-5 Performance Measurement System.

To provide the functional capabilities just described, the C-5 performance measurement system should consist of the following components.

Hardware components:

(1) Cartridge disk system
(2) Minicomputer
(3) Graphic display processor
(4) Image retrieval system (microfiche or video disk)
(5) Display terminals
(6) Data acquisition and control unit (trainer interface)
(7) Touch panels
(8) Keyboards
(9) Printer/terminal

Software components:

(1) Disk operating system
(2) Multitask executive
(3) Display formatting
(4) Image librarian
(5) Performance measurement system modules

Refer to Figure 2 for the performance measurement system configuration.
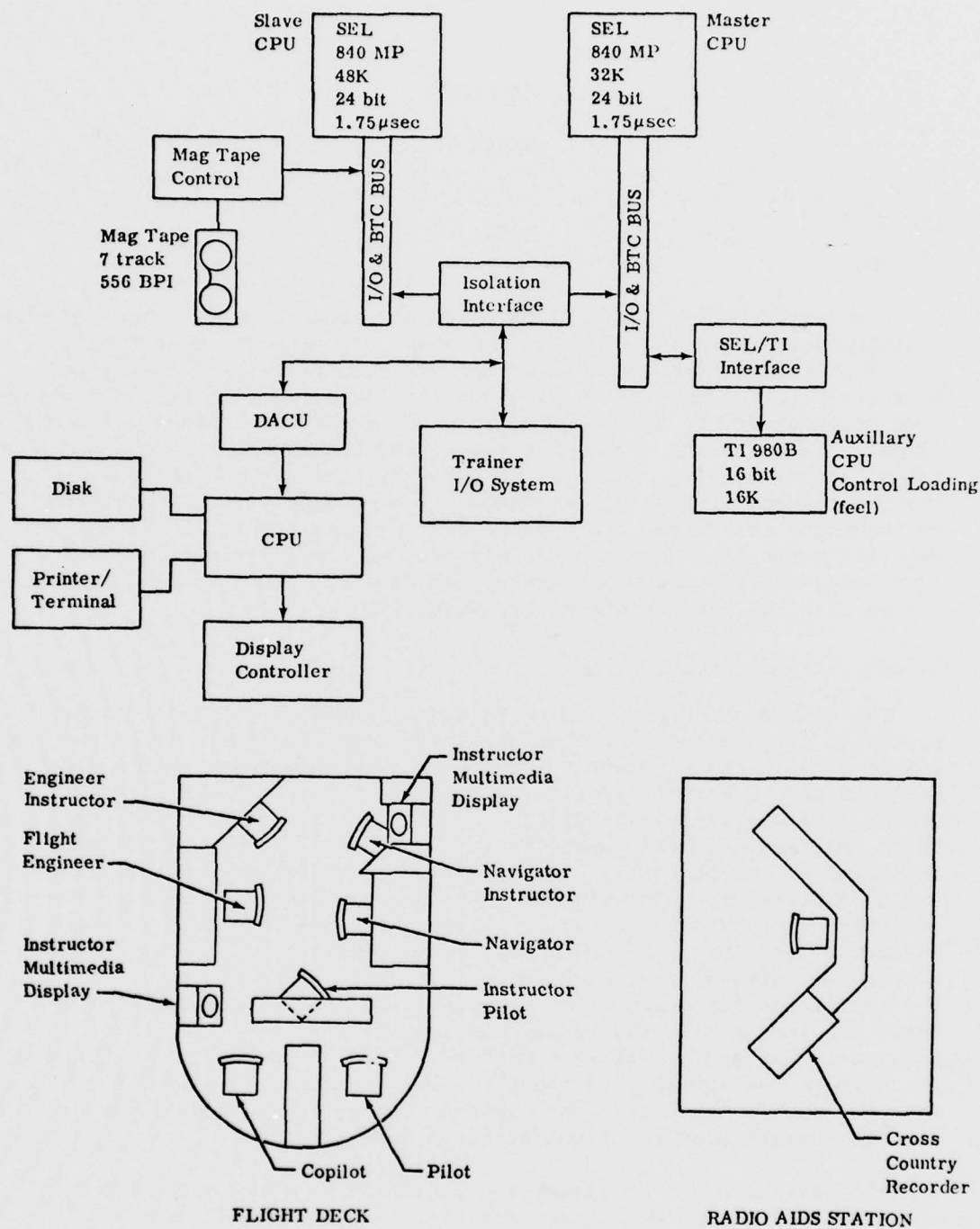
FIGURE 2. Performance Measurement System Configuration D.

SECTION V

PHASE IV

APPROACH

Background

Reviews of Phases I and II revealed performance measurement concerns additional to those specified at the start of contract, specifically: (1) adequate measures or indicants of crew management, as considered separately from crew coordination and (2) identification of representative measures of student performance which might be obtained in actual flight. Based on these considerations, additional efforts were undertaken to: (1) review simulator measurement requirements to determine their applicability to the assessment of proficiency in the airborne environment, (2) define the concept of crew management, (3) define existing capabilities of the C-5 aircraft to provide objective measurement data, and based on these data, (4) develop a functional specification for an airborne performance measurement system.

Review of Candidate Measures

The initial task involved an internal review of the initial work which had defined a set of candidate performance measures for assessing proficiency in the simulator. This set had been derived from a detailed analysis of the essential/critical tasks performed by each aircrew member during a typical airlift mission. In spite of the fact that these analyses had been conducted in the context of operational requirements for a representative line mission, it was recognized that certain unique aspects of the simulation environment may have influenced the selection of candidate measures. It was also possible that various aspects of the inflight regime could have considerable impact on the adopted measurement scheme which would require modification in either the quality and/or quantity of data collected and processed. In view of these considerations, the review was initiated to insure that the previously defined performance measures could be generalized to include the airborne environment and that the measurement set defined for the inflight system would have the highest degree of commonality, compatible with the unique aspects of the airborne flight regime.

The next step was to review the candidate measures with a group of operationally qualified aircrew members. The basic rationale used in the selection of the inital set of measures was explained and the aircrews were asked to conduct their review from the perspective of measuring performance on a typical line mission during which STAN-EVAL examiners were onboard. The aircrew were asked to review the tasks identified in terms that were essential and critical to mission performance and to define any additional inflight tasks which could be

considered that had not been previously specified because of limitations in the simulator. The review process was conducted on a one-to-one basis with a training analyst and the crew members reviewing all phases of flight, segments, and events throughout a representative mission profile. During each session the aircrews were queried concerning the adequacy of the previously defined measurement set and whether there were other essential inflight activities which had not been previously identified. In most cases, since the specific aircrew representatives had not participated in the previous analysis effort during the basic contract, their perspective also served to verify the validity of the initial candidate measurement set.

Analysis of Crew Management

A second task was an attempt to examine the concept of crew management and to determine the extent to which its measurement and/or assessment could be addressed through objective performance measurement techniques. The initial problem was to develop a working definition of crew management based upon the operational doctrine and crew concept of the Military Airlift Command (MAC). Once an acceptable definition was established, the next step was to employ goal analysis techniques in an attempt to develop objective terms to replace the subjective reference to attitudinal or affective domains. This process amounts to prescribing objective behavioral indicators that can be used to attribute and/or infer the manifestation for an attitude or affective trait. Such procedures enable subjective areas to be translated in objective terms which can then be more readily measured and assessed.

This analysis of the crew management concept was conducted in two stages. First, a group of highly qualified C-5 and C-141 aircraft commanders, as well as STAN-EVAL flight examiners, participated in a working session to define crew management. Through group discussions iterative procedures, a definition was developed which all members agreed represented an adequate statement of the MAC concept of crew management; a primary responsibility of aircraft commanders. Based on the mutually agreed-to definition, the group then identified and defined a representative sample of behavioral indicators that could be observed and evaluated during a mission. The second stage involved similar group dicussions with a class of MAC pilots that were attending the Aircraft Commanders Upgrade Course. Similar procedures were followed with this group and the results of the two sessions were used to check the consistency and/or reliability of the process.

Definition of Airborne Performance Measurement System

The third task was to determine the capabilities of the C-5 aircraft which would be available to provide the necessary data to satisfy the requirements of a inflight Performance Meausrement System (PMS). The operation of a performance measurement system requires that certain flight parameters be available for analysis.

a. Preflight checkouts are static tests which should be performed in a prescribed sequence to be effective and obtain the required results to insure the flight readiness of the aircraft.

b. The dynamic events that occur during takeoff, where sequence and control amplitude are important to achieve a takeoff and climb-out that is within the prescribed flight procedures. Each takeoff must be planned and executed based on all the environmental and aircraft loading conditions which exist for that flight.

c. The maneuvers that occur while in an enroute status where navigational proficiency is of prime importance. In this mode, the analysis of the aircraft flight parameters resulting from variations to the flight plan is important.

d. The approach and landing phase is analyzed for deviations to the prescribed standard procedures under the existing conditions.

e. The postflight and shutdown mode is similar to the preflight and is a sequential procedure.

The simualtor performance measurement system equipment makes it possible to directly or indirectly monitor all events that occur from the start of preflight to the termination of the exercise since all events are processed by the simulator computer. A central processing point of this nature does not exist on the C-5 aircraft so alternate methods of evaluation had to be found.

Nonetheless, a system located onboard the C-5 aircraft would provide a more realisitic situation because the evaluation is made at the time of occurrence. This method allows the instructors a closer correlation of the test results to the crew's physical reactions.

The three problems involved in attempting to implement this method are: (1) the interconnection of test equipment and aircraft system, (2) the reliability of performance measurement system equipment operating in an aircraft environment and (3) the flight readiness qualifications of the aircraft following the major modifications involved in adding a performance measuring system.

Another onboard approach is the installation of a special processor/recorder unit to record the inflight parameters required for later evaluation. The same wiring problems are encountered in this method as with the total onboard system. The problem of hardware operation in the aircraft environment is greatly reduced because of the lesser amount of equipment, but the other basic problems of onboard systems remain.

A study was conducted to determine the extent of the system design limitations that would be imposed due to the physical configuration os the C-5 aircraft. A survey of the aircraft wiring found it to be a

point-to-point system with no interconnection junction boxes for signal wiring. This type of wiring system makes it difficult to add new wires since they have to be installed by: (1) planning an additional wire in a connector pin, (2) making a breakout in the equipment and connecting it to an unused pin, or (3) adding a junction box for the required wire and cables. When a large number of signals are required, each of these methods prove prohibitive in the amount of aircraft revision required. At this point, it appeared that the problems involved in installation of an onboard processing system would be both a costly and long term engineering development project.

To overcome the difficulties of adding a special monitoring system to the aircraft, the present systems were reviewed to determine if an alternate method of obtaining the information was available. A preliminary examination of the aircraft system indicated that the malfunctions analysis detection and recording (MADAR) system could supply some of the information and, further, could be modified to provide additional data. One output of the system is the data which are recorded on magnetic tape to be processed later by a land-based computer system. Utilization of this equipment showed promise of providing a satisfactory method of obtaining the necessary flight data without the extreme modifications to the aircraft that the previously defined systems required.

At this point, it was recognized that computer monitoring of all switch settings and event monitoring during preflight and postflight procedures would be prohibitive., Therefore, the definition of a system to analyze performance of the aircrew during inflight conditions was primarily concerned with the events from aircraft stop prior to takeoff to aircraft stop after landing.

The categories of flight parameters for postflight analysis of crew performance would include but not be limited to:

    a. Present aircraft position (Latitude, Longitude)
    b. Aircraft flight parameters (Heading, Altitude, Airspeed, etc)
    c. Environmental conditions (Wind, Temperature, etc)
    d. Control settings (Throttle, Flaps, etc)
    e. Flight Command Signals (Pitch, Roll, etc)
    f. Navigational Aid Signals (TACAN, DME, etc)

A system that could provide real-time monitoring, time annotating, and recording of the foregoing flight parameters would be sufficient for inflight crew performance monitoring.

RESULTS

Review of Candidate Measures

In general, the review of the candidate performance measures, which had served as the baseline of requirements for the simulation measurement system, indicated that they would also provide an adequate basis for the airborne measurement device. This was not unusual since the

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frame of reference for the previous effort had been to develop a measurement set which could be generalized to include operational missions, reflect STAN-EVAL performance criteria for operational quali- fication, and represent the mission essential/critical aircrew tasks for a nominal airlift sortie. However, there were several areas unique to inflight measurement that were identified which should be considered in terms of their impact on data characteristics and measurement techni- ques.

First, since the airborne environment cannot be controlled like the simulator environment, it is not possible to prespecify specific parameter values as performance standards. For example, during simulator operations, the evaluation profile could measure specific values for takeoff and climb airspeeds based upon a preprogrammed gross weight. In the inflight system, the airspeed can be sampled but, because of the wide variety of gross weights, it cannot a priori assess the specific value it should be for a given set of takeoff conditions. This is not a serious limitation because the tolerances for various flight parameters normally remain constant over a broad range, However, evaluation of specific values will probably require a postmission data reduction and analysis scheme. This same situation applies to most of the flight parameters (e.g., heading, altitude, and airspeed.) since they cannot be predefined in the airborne system as they can in the simulator. If the inflight device is to have general application, the means must be provided to accommodate a flexible and adaptable set of conditions and measures.

In terms of those procedural items which are predominantly discrete switch actions, the only change in approach taken is that some items not previously monitored (i.e., circuit breaker settings) should be monitored during the flight. There were also several instances in which simulator limitations led to the elimination of selected items which should not be examined with the inflight system.

Another area which would have impact on measurement was the monitor- ing of navigational activities. In the simulator environment, it is always possible to obtain the actual position and use it to assess an error in navigation. In the airborne environment, there is no means of checking the navigator's performance. The procedural steps could be monitored as long as they involve switch positions on the NACV panel of the IDNE. However, if the navigator is engaged in strictly manual navigation (i.e., unaided by a navigation computer, such as a manual radar), it is uncertain whether such activity can be monitored without extensive aircraft modification. This was not a problem in the simula- tor because almost all switch position had a digital interface to the host computer. The problem associated with monitoring the navigator's activities may be solved by the incorporation of a triple INS which will either eliminate the navigator's role or insure that the vast majority of the navigation activities are performed in conjunction with the IDNE computer through the MADAR, which could then be monitored in the air.

In general, the results indicated that the requirements previously defined for the simulator performance measurement system could be applicable to the inflight measurement system. As previously indicated, there were several unique aspects of the airborne environment which could impact measurement techniques but the performance requirements are basically the same in terms of the aircrew activity and duties. However, it does appear that the major difference between the two systems would be the need for a postmission analysis of the recorded flight information in order to adequately evaluate the aircrew's performance during the mission.

Analysis of Crew Management

The preliminary discussion that preceded the development of a definition of crew management indicated that individual qualities such as leadership, decisiveness in decision making, management style, and skill in interpersonal relationships, were the main characteristics required of aircraft commanders. The concsensus was that a blend of operational authority combined with the respect of the aircrew were crucial in crew management.

The basic definition of crew management agreeded to by the aircraft commanders was: "the demonstrated ability to establish and maintain effective crew discipline throughout the entire mission." The specific clarification given to certain definition terminology was that "demonstrated ability" referred to the fact that aircraft commanders never actually have the authority or responsibility for aircrew discipline until after aircrew members are certified. However, in previous instances, aircraft commanders have demonstrated an ability for leadership as a basis for the selection for upgrading by their superiors. The terminology "effective crew discipline" refers to the balance between authoritarianism and democracy in dealing with crew matters whether they be operational or interpersonal in nature. The "crew discipline" terminology was further defined as: insuring that all crew positions perform their duties in a timely, orderly, and professional manner. Finally, the terminology "throughout the entire mission" applies to the period from the time the aircrew was alerted until they return to their home base and are debriefed.

There was general agreement that no specific objective measures could be identified as a unique indicator of crew management. However, the feeling was that certain situations could be observed and subjectively evaluated as a manifestation of effective crew management. The indicators would be how well the aircraft commander analyzed the situation and handled the decision making process; for example, the actions he takes upon discovering that the fuel management log indicated insufficient fuel to make the original destination as planned. The method used to diagnose the situation and the decisions leading to corrective action would provide a good indicator of the aircraft commander's crew management techniques. Other general indicators would be the manner in which he advises the command post of problems.

For example, if he contacted them with a predetermined course of action and stated his intention rather than merely advising them of the situation and requesting guidance, then effective crew management would be indicated. Additionally, if he made it clear to the crew that standard radio terminology and procedures were essential to crew coordination, and insured that such practices were followed, he would be demonstrating effective crew discipline. Hence, the outcome of this examination of crew management indicated that situational analysis supported by the subjective evaluation of the aircraft commander's decisions could provide a positive indication of crew management that would be adequate for assessing proficiency.

There was additional indication that aircraft commanders are expected to demonstrate a higher degree of flying proficiency. This could be objectively measured with a simulator performance measurement system by tightening tolerances. In general, the major influence of a performance measurement system was recognized as the ability to set up and control situations in the simulator which could be observed and subjectively evaluated by a flight examiner. The system would free the examiner from routine monitoring activities and allow him to concentrate on the subjective evaluation of judgement, leadership, decision making, etc; which are difficult to assess objectively.

Definition of Airborne Performance Measurement System

The objective was to describe a system that would provide the necessary flight parameters to allow measurement of crew performance during training flights. The result of these efforts led to the definition of a configuration that would obtain the necessary data for a postflight evaluation of the aircrew's flight proficiency. The MADAR system could be modified to provide this capability.

MADAR System Operation. The MADAR is a computerized data collection, processing, and recording system. The data collection part of the system has 22 signal amplifier units located throughout the aircraft. Each amplifier has 29 analog inputs and upon command it selects one of 29 parallel analog input signals and transmits it to the central multiplexer assembly (CMA). The CMA controls the multiplexing of the signal amplifiers and digitizes the analog signals for computer operation. The computer separates the digital signals into categories of analog and discrete signals. The discrete signals are utilized for their high/low characteristics, and the analog signals are analyzed on their absolute value. The constant recording of all values required to be recorded is beyond the capability of the system, so the MADAR system uses a trending technique for selection of the value to be recorded.

The initial condition of the discretes is recorded and only the changes of state are recorded after the initialization. The initial value of the analog signal is stored in the computer and recorded on the magnetic tape. After this initial value is processed, the computer performs a trend analysis on all future values.

In the trend analysis a ± variance is added to the original value to establish the high and low limit. The value of the signal is not recorded until it exceeds the variance value. When it does exceed the variance limit, the new value is recorded on the magnetic tape and established in the computer as the new base value. The allowable variance for each function is pre-assigned and is based on the uses of the recorded values. As an example of this trending operation, assume a mach number of .600 with an allowable variance of ±.010. A change in value of the function will not be recorded until it goes outside the .59 to .61 boundary limit. If the value jumps to .612, then this value is recorded on the magnetic tape and established in the computer as the new base. The computer now uses .602 and .622 as the new boundary limits. This technique allows many functions to be monitored with a limited amount of recording speed and tape storage. Since the signals are all monitored at least once per second, the trending operation produces a nearly continuous monitoring of all functions.

Flight Analysis Requirements. The flight parameters recorded on the magnetic tape could be used to reconstruct a real-time flight in a ground-based computer. To complete this function for further analysis, as a minimum, the real-time coded values of the following flight parameters are required:

    a. Latitude
    b. Longitude
    c. Ground Track Speed
    d. Ground Track Heading
    e. Indicated Airspeed
    f. Aircraft Heading
    g. Aircraft Pitch
    h. Aircraft Roll
    i. Aircraft Yaw
    j. Aircraft Barometric Altitude
    k. Wind

For performance measurement analysis of the aircrew proficiency, the real-time coded value of the following flight parameters are required:

    a. Throttle Angle
    b. Core Speed N_2
    c. Fan Speed N_1
    d. Squat Switch
    e. Glideslope Deviation
    f. Localizer Deviation
    g. Go-Around Computer Deviation
    h. Radar Altitude Above Ground
    i. Vertical Velocity
    j. Nose Landing Gear Angle
    k. Main Landing Gear Angle
    l. Nose Landing Gear Weight
    m. Main Landing Gear Weight
    n. Fuel Flow Rate

o. Rudder Position
p. Elevator Position
q. Aileron Position
r. Wing Flap/Slat Position
s. Air Temperature
t. Ignition Current
u. Lateral Acceleration
w. Pitch Command
x. Roll Command
y. TACAN Range
z. TACAN Bearing

Most of the foregoing signals are available on the MADAR magnetic tape; however, some are not.

Signals Unusable or Unavailable Through the MADAR System. The following paragraphs identify the signal information not available through the MADAR system.

Present Position Information. The latitude/longitude information is transmitted once each second from the Inertial Doppler computer to the MADAR computer. It is recorded on the magnetic tape once every 15 minutes. The frequency of this input is considered insufficient, therefore, the MADAR computer program will be changed to output these values more frequently. A trade-off study will have to be made to determine the required frequency of recording.

Signals Available Through the IDNE computer. The following signals are not available in the MADAR system, however, they are available in the IDNE computer in a high-precision form.

a. Ground Track Heading
b. Ground Track Speed
c. Aircraft Heading
d. Aircraft Pitch
e. Aircraft Roll
f. Aircraft Yaw
g. Wind

There is a data transfer link from the IDNE computer to the MADAR computer which transfers eight words of information once each second. The first five words are 28 bits each of discrete signals showing the performance validity of systems aboard the aircraft, the sixth word is the status of the IDNE computer batteries, and the last two words are the aircraft present position latitude and longitude.

This data link could be used to transfer the required information by a change in the IDNE and MADAR computer programs. There are several bit positions available in the five discrete words, that could be used to indicate the information which is being transferred in words 7 and 8 during that cycle. The required information could be sequentially placed in words 7 and 8 in lieu of the latitude and longitude being

transferred on every cycle. Although this would require a computer program change, the accuracy of the signals would be greater than could be obtained through other methods. Further, aircraft wiring changes would not be required.

During discussions with Air Force personnel, it was indicated that a change from the present IDNE Navigation system to a triple INS Carrousel system is scheduled for implementation by 1981. If this occurs, it will change the method of obtaining the navigation parameters defined previously, but they would all be accessible from outputs of the new system. A system could be designed to mate with either the current or future system but it would not be interchangeable between the systems.

Signals Available Through the Flight Instrumentation System. The following signals are not available in the MADAR system but are available through the Flight Instrumentation System:

a. Glideslope Deviation
b. Localizer Deviation
c. Go-Around Computer Deviation
d. Roll Command
e. Pitch Command
f. DME Range
g. TACAN Bearing

The signals could be added by connecting their most convenient source to vacant channels of a signal amplifier unit. The Central Multiplexer Assembly would then accept the signals for trend analysis by the MADAR computer, and the results would be recorded on magnetic tape.

Instructor Annotation.

The MADAR system has the capability for an operator to log one-word messages on the magnetic tape. This one-word message is coded to time annotate a certain type of condition aboard the aircraft. The message is inserted through a pushbutton keyboard on the Control and Sequencer Unit. All keyboard entries are processed by the MADAR computer, and if the first two digits are 31 followed by five digits, the number is recorded on the magnetic tape with no further action taken by the computer. The ground computer could analyze the signal and establish the condition that was reported during the flight.

The MADAR recording would be continuous from the time of preflight until postflight shutdown. Each flight would consist of one complete flight plan or could be a composite of several short sorties. For a complete flight, the scenario would define all conditions and functions that are to be performed from preflight to shutdown. On short exercises during a flight, the flight instructor would instruct the aircrew members when to perform a maneuver. At the same time the instructor would provide an annotated input to be recorded by the MADAR system as

previously defined. This recorded annotation would identify to the performance measurement system computer the exercise that will be performed. The system would conduct the performance measurement analysis based on the aircraft conditions at the time of the Instructor's message.

The performance measurement system computer would compare the actual flight with the predefined scenarios and the aircrew performance would be evaluated on their correlation. At the conclusion of an exercise, another exercise could be selected by the instructor and the same annotation routine followed.

Flight Data Recording.

The MADAR data recorder is a special product to be used as a part of the inflight system. It is designed to the specifications of the MADAR flight system and the tape form and format msut be compatible with commercial magnetic tape readers. The recorder is controlled by the MADAR computer and operates as a slave to the unit. The computer analyzes the data it receives from all sources and determines which items are to be recorded. Upon determination that an item fulfills the requirement to be recorded, the computer formats and stores the data in its memory to await transfer to the recorder. The computer contains two buffer registers (A and B) which it uses for this memory function. Each register contains 640 bytes of 6-bit length. The computer alternately fills the registers with the data to be recorded. When a buffer is full, the computer starts storing in the alternate buffer. The recorder is turned on, and the contents of the full buffer are transferred for recording. The buffer is then cleared and ready for future use. As the buffers are of fixed length, an event message may be split into the two buffers. The ground-based computer will be required to reassemble the messages.

The recorder operates at a nominal record speed of 300 characters per second. It is powered by stepping motors and records one character (6 bits plus parity) at each increment. The data is received from the computer, one character at a time, in synchronism with the recorder operation. The recording is made on the tape at a density of 556 characters to the inch. The recorder formats the data on the tape into records of 640 characters each as defined by the computer buffer registers. After each record, it produces an end-of-record code and a blank strip of approximately 421 spaces. This blank strip, approximately 3/4 inch, is used to provide a stop for the reader without losing recorded data, thereby allowing the computer to process the data contained in the record before receiving the next record. The collection of records made during a flight is called a file. An end-of-file marker is placed on the tape at the conclusion of the flight. The recorder provides a parity check in each character, end-of-record code, and in the end-of-file code.

The standard 1/2-inch-wide tape used by the system is 2400 feet in length and stored on a 10 1/2-inch reel. The reels are mounted in carrier for use with the inflight system. To read the tapes, the reels

must be removed from the carriers and mounted directly on a commercial tape reader, which must be capable of operating with 7-bit NRZI recording having a bit density of 556 bits per inch.

Ground-Based Computer Operation.

The tape will be read and input to the performance measurement system computer in an off-line operation. The MADAR tapes contain information that is not used by the performance measurement equipment and also data that are not used by the MADAR data bank computer. Prior to performing any performance measurement evaluation, the performance measurement equipment will read the flight tapes and sort the information into two files, one that is required by the performance measurement equipment and one that is used by the MADAR data bank computer. Some data will be used by only one system and some will be used by both. After separation, the MADAR information will be stored for writing onto a tape for transmittal to the MADAR data bank computer.

The information that is selected by the sort routine for performance measurement usage will be formatted and stored for use in creating a real-time profile of the flight. The stored data will provide the performance measurement system computer with the flight profile and events to compare with the flight scenario profile for aircrew performance evaluation.

Ground System.

The ground equipment for the inflight system could utilize the C-5 simulator performance measurement system for evaluation of the flight. Additional equipment will be required to adapt the simulator performance measurement equipment to handle the inflight evaluation. A new computer program will be required to generate the flight profile. The program used to perform the simulator performance measurement will be modified to perform the inflight performance measurement analysis.

The additional equipment will include a magnetic tape reader and magnetic disk memory. The magnetic tape reader will be used to read the tape recorder inflight and to record the selected information on the tape to be used by the MADAR data bank.

An additional disk memory unit will be added to the system for storage of flight data during the sort memory and for storing the flight parameters for use during the flight evaluation.

SECTION VI

SUMMARY

In Phase I of the study, the aircrew tasks and performances essential to effective operation of the aircraft were translated into a candidate set of performance measures for ensuring aircrew proficiency. The accomplishment of this objective required three separate but interrelated efforts: (1) the determination and segmentation of a representative mission profile, (2) the determination of aircrew activities within each segment and (3) the determination of mission-essential/critical aircrew tasks and duties among these aircrew activities.

The completion of these tasks provided an ordered listing of crew-member tasks and duties that are essential or critical to the typical C-5 operational mission and that constitute the complete set from which those items to be measured can be selected. Once these crew tasks and duties were established and verified, the requirements for their measurement and evaluation were considered. These requirements are concerned with measurement processes, characteristics of the performance data, the scheme for collecting the data, etc.

Validity of the performance measures were defined in terms of their relation to underlying skills and proficiencies required for operational qualification. Reliability of the measures was defined in terms of their stability and precision, which are necessary properties for discrimination among various levels of performance, given repeated measures of this performance. The performance data were also categorized in terms of discreteness versus continuity of the tasks themselves, and measures appropriate to each were discussed. Other considerations were representativeness of the performance data, measurement priorities in cases of conflicting measurement requirements, and variable measures of the same skill. Finally, preliminary consideration was given to the configuration of the system itself in terms of projected hardware and software and the eventual mutual impact of the system and measurement requirements upon each other.

In Phase II, the capabilities of the current C-5 simulator to measure performance were assessed and a determination made regarding how to augment the system to take advantage of these capabilities. These efforts started with a review of the performance measurement requirements by systems engineers to determine the nature and type of data, sources format, extraction rates, etc. to be handled by the system. Next, an on-site visit to the simulation facility at Altus AFB provided an opportunity for an engineering review of general simulator capabilities and limitations. The results of this review provided a description of the present system's potential for measuring aircrew performance. This potential was assessed in terms of the ability to monitor and process

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the types of performance data identified as candidates for measurement in Phase I. Estimates of the computational requirements for a performance measurement subsystem were based on both the measurement functions and data characteristics of the candidate measures. General recommendations were made at this time, such as the implementation of a high-level programming language for the measurement subsystem in order to reduce initial programming cost and to enhance system flexibility to accommodate future changes.

In the process of defining alternative configurations of hardware/software for performance measurement, one option was presented for using existing simulator processors, and four were presented as independent and autonomous in the sense of using their own processors. These latter systems would ride "piggyback" on the basic simulation system and would thus constitute performance measurement subsystems. Each of the five was specified in terms of hardware and software requirements.

The latter four were specified in ascending order to lesser to greater performance measurement capabilities, lesser to greater flexibility, and lesser to greater utility. They were all presented for review by the Air Force as a spectrum of performance measurement system/subsystem candidates.

In Phase III, the results of Phase I and II were synthesized into a description of the functional and engineering requirements of the system configuration selected for further consideration by the Air Force. The configuration selected for development provides the following capabilities:

a. <u>Performance measurement</u> - monitors all switch positions, control settings, and instrument readings, and provides access to selected flight parameters such as airspeed and/or geographic position.

b. <u>Debriefing report</u> - provides objective/quantitative performance data which the instructor may use to assess and evaluate performance.

c. <u>Data collection</u> - allows for a range of uses of the performance data, including instructional, statistical/analytical, and comparative/evaluative.

d. <u>Mission sequence display</u> - shows the sequence of tasks performed by means of image retrieval, alphanumeric capabilities, or both.

e. <u>Error alert display</u> - automatically alerts the instructor/evaluator to crew errors as they occur.

f. <u>Problem control</u> - automates problem set-up and preselection and insertion of malfunctions.

g. <u>Checklist and route chart display</u> - provides quick access to any of a large number of checklists and route charts associated with ongoing tasks.

In Phase IV of the study, performance measurement requirements for the simulator measurement system were reviewed. It appears that the same general set of candidate measures would be applicable to an inflight measurement system. There were a few additional measures identified, but the major impact on the requirements will relate to measurement techniques rather than to specific data elements per se. In general, the measurement scheme cannot incorporate predefined flight profiles or parameter values for evaluation purposes, but rather, will monitor and record discrete values of selected flight parameters and events as they occur which can then be processed and evaluated during a postmission data analysis. Such an approach will additionally require that selected parameters be sampled at regular time intervals during the flight profile, since the system cannot precisely control the occurrence of various flight segments, as is done in the simulator. These sampling rates will be a function of the flight segment and will be dictated by the quality of the measure involved for evaluation purposes. In essence, the measurement concept for the inflight device will be less active and basically serve as a passive monitor of aircrew activity.

The C-5 inflight performance measurement can be obtained through several methods. The methods analyzed in this study ranged from designing a new airborne flight qualified analysis system to a method where no new flight equipment would be installed aboard the aircraft. The latter method was selected as a recommended system to minimize the system cost and implementation time. It appears that the C-5 MADAR system, which routinely monitors approximately 19 parameters and has the ability to interrogate a number of key switch positions, will provide a feasible basis for interfacing the inflight measurement system with the C-5 system components. The commonality of the inflight and simulator systems and the evaluation programs will achieve correlation of student performance in the simulator and in the aircraft that could not be obtained in two independently designed systems.

APPENDIX A

CANDIDATE PERFORMANCE MEASURES

I. PREFLIGHT AND STARTING PHASE

A. PILOT/COPILOT ACTIVITIES

1. Before starting engines checklist:

Thrust reverse limiter set to 4.7.
Brake supply selector to ANTI-SKID.
Set parking brake, emergency light ON, and pressure OK.
Paradrop and ADS panel switches SAFE.
Nav. light ON steady.
Anti-collision light on ALL.
Inboard elevator #2 and #3 switches OFF.
Windshielf head switches NORMAL.
Seat belt light switch on light ON.

2. Starting engines checklist:

Starting button IN (1 minute on, 30 seconds off, three times or 2 minutes on, 5 minutes off).
Fuel and ignition to RUN at 11% N_2RPM.
Fuel flow to 700#/hour or less.
TIT raise within 30 seconds, otherwise abort. (Starter button should pop out at 45%; if it fails to, it must be pulled out by 61-66%.)
TIT within limits of 800 - 860 for 25 seconds, over 860 for not more than 2 seconds.
N_1 rotation occurs within 5 minutes of idle RPM.

REPEAT PROCEDURES FOR EACH ENGINE.

Continuous ignition switch ON.

B. NAVIGATOR ACTIVITIES

1. Interior inspection checklist:

MANUAL GROUND ALIGNMENT
IDNE mode switch to "STBY" or "GRD ALIGN."

Enter present position:

>   Enter select - <u>PRES POS</u>.
>   Display select - <u>PRES SIT</u>.
>   Norm/Altn - <u>NORM</u>.
>   Enter latitude - <u>39°08'N</u>.
>   Enter longitude - <u>75°28'W</u>.
>   Display select - <u>SPECIAL DATA</u>.
>   Enter field elevation - <u>28</u>.

AUTO GROUND ALIGNMENT

IDNE mode switch to <u>INRTL DOP</u> or <u>INRTL</u>.
Enter present position:

>   Enter select - <u>PRES POS</u>.
>   Display select - <u>PRES SIT</u>.
>   Norm/Altn - <u>NORM</u>.
>   Enter latitude - <u>39°08'N</u>.
>   Enter longitude - <u>75°28'W</u>.
>   Display select - <u>SPECIAL DATA</u>.
>   Enter field elevation - <u>28</u>.

Doppler test button Depressed.
AHRU mode select switch to <u>CMPS</u>, <u>DG</u>, or <u>SLAVE</u>.
Radar X and K function switches <u>not</u> to TEST simultaneously.
LORAN display test Depressed (momentary).
Proper station and time difference readouts displayed.
Enter IDNE destination data:

>   Enter select - <u>DEST</u>.
>   Display select - <u>DEST</u>.
>   Norm/Altn - <u>NORM</u>.
>   Enter DP# - _____.
>   Latitude - _____.
>   Longitude - _____.

Enter RADAR FIX data:

>   Enter select - <u>RADAR</u>.
>   Display select - <u>FIX DATA</u>.
>   Norm/Altn - <u>NORM</u>.
>   Enter fix point # - _____.
>   Latitude - _____.
>   Longitude - _____.
>   Elevation - _____.
>   Variance code - _____.

Enter TACAN FIX data:

 Enter select - <u>TACAN</u>.
 Display select - <u>FIX DATA</u>.
 Norm/Altn - <u>NORM</u>.
 Fix point # - _____.
 Enter latitude - _____.
 Enter longitude - _____.
 TACAN FP altitude - _____.
 TACAN channel - _____.

Enter LORAN fix:

 Enter select - <u>LORAN</u>.
 Display select - <u>FIX DATA</u>.
 Norm/Altn - <u>NORM</u>.
 LORAN FP # - _____.
 LORAN FP latitude - _____.
 LORAN FP longitude - _____.
 LORAN time delay _____usec then ALTN & _____musec.

Enter celestial fix:

 Enter select at <u>CELST DATA</u>.
 Display select at <u>SPECIAL DATA</u>.
 Norm/Altn at <u>NORM</u>.
 Code # GHA of body _____.
 Enter GHA of Aries (Y).
 Enter code # GTAT start time _____.

C. FLIGHT ENGINEER ACTIVITIES

 1. Interior inspection checklist:

  Turn on and check radio:
   Monitor or check tower or Ground Frequency (327.5 or
  275.8).

  Check engine and APU Fire Detection System:

   Test switch to <u>FIRE</u> at beginning of check.
   Test switch to <u>ENGINE OVERHEAT</u> at end of check.

  Test Short Discriminator Test Switch:

   Test switch to <u>TEST</u>.
   Fire Detect switch to <u>FIRE</u>.

  Start APUs and apply APU power:

   APU Bleed Valve switches to <u>CLOSE</u>.

Start APUs and apply APU power:

    APU Bleed Valve switches to <u>CLOSE</u>.
    APU GEN SELECT switch to <u>LAPU</u>.
    External Power switch to <u>EXT PWR</u>.
    On Speed light Illuminates.
    Voltage and Frequency Normal.

(Note: For right APU procedures are identical except for
       second step above: switch to RAPU.)

    APU power switch to <u>APU</u>.

Test F. E. caution lights:
    Switch to <u>TEST</u>.

Check O_2 quantity:
    Test buttons Depressed.

Engine Ice Control switches of <u>OFF</u>.

Environmental Control Panel Set:

    Left and Right manifold pressure <u>NORMAL</u>.
    Left Overheat test switch to <u>TEST</u>.
    Left Iso Valve Closed light ON and OFF.
    Right Overheat test switch to <u>TEST</u>.
    Right Iso Valve Closed light ON and OFF.
    L APU bleed valve switch <u>CLOSED</u> and <u>OPEN</u>.

Pressurization System Check:

    Outflow valve switch <u>OPEN</u> and <u>CLOSED</u> and <u>OPEN</u>.

(Note: Fuel panel setup omitted in favor of fuel quantity
       check.)

Check Fuel Quantity Indicators:

    Push-to-test button pushed with fuel stop at 50%.
    Push-to-test button pushed with fuel stop <u>not</u> at 68%.

#1 and #4 Main Tank Sump Low Test:

    Switches to TEST 1.
    Switches to TEST 2.

Fuel Valves and Fuel Pumps check:

    Left manifold pressure at 25 - 48 psi.
    Left manifold pressure at 0 psi.

(Note: This sequence is repeated 24 times when correctly
accomplished.)

Main Tank Boost Pump Switches to ON.

Set Hydraulic Panel:
PTUs to OFF. (Note: All checks are visual.)

ATMs ON:

Hydraulic Boost Pumps ON.
#1 and #4 Hydraulic Systems Pressure 3000+150 psi.
Hydraulic Boost Pumps OFF.
#1 and #4 Hydraulic Systems Pressure 3000+150 psi.
Hydraulic Boost Pumps ON.

Hydraulic System #2 pressurized to 2500 psi:
Systems 1 and 2 PTU ON.

Hydraulic System #3 pressurized to 2500 psi:
Systems 3 and 4 PTU ON.

Fire Suppression System check:

ARM switch to ARM.
ARM switch to PANEL SAFE.

Vent Valve Sequence check:

Left Wing Vent Valve Open:
Depress and Release pushbutton - FSS panel.

Left Wing Vent Valve Closed:
Depress and Release pushbutton - FSS panel.

Right Wing Vent Valve Open:
Depress and Release pushbutton - FSS panel.

Right Wing Vent Valve Closed:
Depress and Release pushbutton - FSS panel.

Fire Warning check:

Nitro Fire Suppression switch to DETECTOR DISCHARGE.
Nitro Fire Suppression switch to OFF.

Optical Reset:

Reset switch to RESET.
Reset switch to OFF.

Warning Horn Test:

    Switch to HORN TEST.
    Switch to HORN SILENCE.

Wheel Well Fire Detection System:

    Test switch to DETECTOR DISCHARGE.
    Test switch Released (to spring loaded position).
    Test switch to DETECTOR DISCHARGE.
    Test switch Released (to spring loaded position).

Annunciator and Word Warning Lights check:

    Caution Lights Test switch to TEST.
    Caution Lights Test switch to OFF.

Reverse Thrust Emergency Retract switches test:

    Switches to NORMAL.

Landing Warning Horn and Lights Test:

    Depress and Release pushbutton.

Nose Landing Gear Steering Switch check:

    Switch NORMAL (visual check only).

Engine Fire Controls Set:

    Fire Handles IN (visual check only).
    Bottle Select Switches NORM (visual check only).
    Bottle Out Lights OFF (visual check only).

Parking Brake Set:

    Brake Switch to EMER (visual check only).
    Brake Handle BACK.

Brake and Anti-skid System Check (Test 1):

    Brake Switch to ALT.
    Brake Switch to NORM.
    Anti-skid Switch to TEST ARM.
    Test 1 pushbutton Depressed;

        No Brake light illuminates within 3 seconds
    (critical visual check).
        Det. Failed light ON (critical visual check).

Test 1 pushbutton Released.

Brake and Anti-skid System Check (Test 2):
    Repeat above sequence.

Brake and Anti-skid System Check (1 and 2 button test):

    Pushbuttons 1 and 2 Depressed:
        Brake Lights ON (critical visual check).

    Pushbuttons 1 and 2 Released.

Brake and Anti-skid System Check (Test 3):

    Test 3 pushbutton Depressed:
        Anti-skid Off Light ON (critical visual check).

    Test 3 pushbutton Released.
    Anti-skid Switch ON.
    Brake Switch to EMER.
    Anti-skid Switch OFF.

Check Flight Controls:

    Stall Limiter Test Switch to TEST 1. ⎫
    Control Column Shake.   ⎬ Simultaneous
                                          ⎭

Set PACS Pitch and Toll Switches:
    Switches OFF to NORMAL.

Continue Flight Controls Check:

    Inboard Elevator Hydraulic Power Switches to OFF.
    Right System 2 Hydraulic Power Switch to NORMAL.

Climbing Left Turn Check:

    Control Column to BACK.
    Full Left Aileron.
    Left Rudder.

Flaps Check:
    Flaps handle to LAND Position.

Set Inboard Elevator Left System 3 Hydraulic Power:

    Power switch to NORM.
    (All other switches OFF for additional check).

Diving Right Turn Check:

    Control Column to <u>FORWARD</u>.
    Full Right Aileron.
    Right Rudder.

Set Inboard Elevator Left System 2 and Right System 3
Power Switches:

    Switches to <u>NORM</u>.
    Column movement <u>Fore</u> and <u>Aft</u>.

Ground Spoiler Check:

    Handle to <u>OPEN</u> position.
    Control Wheel movement <u>FULL L & R</u>.

Aileron Trim Check:

    Aileron Trim Delect Switch to <u>BOTH</u>.
    Trim Knob Slide Bar to <u>HOT</u>.
    Trim Knob Slide Bar to <u>GND</u>.
    Trim Knob Slide Bar to <u>NEUTRAL</u>.
    Trim Knob Position to <u>LWR LEFT WING & LWR RT WING</u>.

Rudder Trim Check:

    Power switch to <u>NOSE LEFT</u> and <u>NOSE RIGHT</u>.
    Ground switch to <u>NOSE LEFT</u> and <u>NOSE RIGHT</u>.
    Both switches to <u>NOSE LEFT</u> and <u>NOSE RIGHT</u>.

Pitch Trim Check:

    Stabilizer trim switch to <u>NORM</u> and <u>ALTR</u>.
    Pilot's Power Trim switch to <u>NOSE UP</u> and <u>NOSE DN</u>.
    Pilot's Ground Trim switch to <u>NOSE UP</u> and <u>NOSE DN</u>.
    Both switches to <u>NOSE UP</u> and <u>NOSE DN</u>.
    Pilot Trim Disc (pushbutton) Depressed.
    Trim switch to <u>NORM</u> and <u>ALTR</u>.

Manual Trim Check:

    Pilot's Manual Trim Switch Depressed; lever Full Aft.
    CP Manual Trim Switch Depressed; lever Full Forward.

Alternate Pitch Trim Check:

    Alt Trim Test Switch to <u>TEST 1</u>.
    Trim switches to <u>NOSE DOWN</u>.
    Alt Trim Test Switch to <u>TEST 2</u>.

Trim switches to NOSE DOWN.
Alt Trim Test Switch to TEST 3.
Elec. Stab. Trim switches to NOSE DOWN.

Position Indicator Check:
Stabilizer position indicator to 0°.

Engage Flight Augmentation System:

Yaw pushbutton Depressed.
Pitch pushbutton Depressed.
Lateral pushbutton Depressed.
Reset/Fail pushbutton Depressed.

Rudder Hydraulic Power switches set:
All four switches to NORM.

Yaw Augmentation Manual Trim Control Check:

Trim switch to ARM.
Rotate Trim Control Left - Right.

Rudder Travel Check:

Trim switch to OFF.
Rotate Trim Control NOSE LEFT, NOSE RIGHT, 0.

Aileron and Inboard Elevator Left System 2 and Right
System 3 Hydraulic Power Switches:
Power switches to NORM.

(Note: Critical step which marks the last step of Flight
        Augmentation System Tasks.)

ALDCS Check:

(Note: Not accomplishable in the simulator.)

Auto Pilot System Check:

AFCS Master Power pushbutton Depress and Release.
Pitch pushbutton Depress and Release.

Pilot's A/P Disconnect pushbutton Depress and Release.
Auto Pilot Re-engage:

Disconnect pushbutton Depress and Release.
Pitch pushbutton Depress and Release.
Lateral pushbutton Depress and Release.

Copilot's A/P Disconnect pushbutton Depress and Release.
    (Note: Repeat Auto Pilot Re-engage procedure).

Control Knob Rotation LEFT, RIGHT, CENTER.
Wheel CENTER.
Auto Pilot Pitch Wheel Rotation NOSE UP and NOSE DOWN.
Altitude Hold pushbutton Depress and Release
Pitch Trim switches NOSE UP and NOSE DOWN.
Auto Pilot Pitch Re-engage:
    A/P Pitch pushbutton Depress and Release.

Yaw, Pitch, Lateral Augmentation pushbuttons Depress
and Release.
Pitch pushbutton Depress and Release.
Lateral pushbutton Depress and Release.
AFCS Master Power pushbutton Depress and Release.

CDPIR Check:

    CDPIR Monitor switch PULL.
    Test Battery switch CHARGE, then VOLTS,
    Bite pushbutton Depress.

Set Pilot's Side Console:

    Parking Brakes RELEASE.
    PTU switches OFF.
    ATM switches OFF.
    Systems 1 and 4 Hydraulic Boost Pump switches OFF.

Pilot's Overhead Console Check:

    No Smoking/Seat Belt lights ON.
    Seat Belt lights OFF.
    P & CP Pilot Heat and AOH De-ice switches ON and OFF.
    Bailout Alarm switch ON and OFF.

AHRUs Check:

    Mode switch DG, SLAVE, and SYNC.
    (NOTE: Repeat steps for other AHRU.)

Set NAV Console:
    (Note: visual checks only.)

Check and Set MADAR:

    MADAR pushbutton Depress.
    Film Display pushbutton Depress.
    Keyset Clear pushbutton Depress.
    System Status pushbutton Depress.

Standby Mode pushbutton Depress.
MADAR TEST pushbutton Depress.
Standby Mode pushbutton Depress.

II. TAXI AND BEFORE TAKEOFF PHASE

A. PILOT/COPILOT ACTIVITIES

1. Before taxi checklist:

Flight augmentation Engaged.
Lateral fault light remains ON.
Pilot resets augmentation switch.
Insure normal brake pressure; switch normal, 3000+150 psi.

2. Taxi:

("CROSSWIND ASSEMBLY MALFUNCTION" inserted causing the
main landing gear to fail to center after the initial taxi turn.)

Crosswind reset switch: RESET.
Takeoff data updated, set T.O. EPR to 4.54+1.

3. Before takeoff checklist:

Flap handle to 40% down.
(Slat disconnect malfunction is inserted.)
Retract flaps.
Flaps to 40% (removes malfunction).
Pilot and copilot Nav. Selector Panel: VOR and HDG selected.
P & CP BDHI: TACAN #1 and VOR #2 selected.
#1 VHF NAV to SEA ISLE 114.8.
#2 VHF NAV to WATERLOO 112.6.
RADAR ALT set to 300'.
RAT to AUTO.
Set stabilizer trim to 2.75+.25.
Check rudder limit switch to AUTO.

B. NAVIGATOR ACTIVITIES

1. Before taxi checklist:

Enter 222 and ENT (Sea Operations) or INRTL Mode.
Select STBY on MMR.

2. Before takeoff checklist:

X band function selector to OPR (MMR panel).
WX mode selected.
60 mile range.
IDNE proper horizontal steering mode selected:

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Enter select to <u>PRES POS</u>.
Display select to <u>DEST</u>.
Norm/Altn to <u>NORM</u>.
DP #_____.
Depress TRACK or DESTINATION STEER.
Set altimeter.

C. FLIGHT ENGINEER ACTIVITIES

1. Before taxi checklist:

A/C MASTER switch to <u>BOTH</u>.
Recirculation Fan to <u>ON</u>.
Nose landing gear switch to <u>HI SHIFT</u> and <u>TEST</u>.
PTUs <u>ON</u> (#3 and #4).
Depress both boost pumps, #1 system and #4 system, then
back to <u>NORM</u>.
Engine anti-ice switch <u>ON</u>.
Ice detector controller switch to <u>AUTO</u>.
Engine anti-ice switch <u>OFF</u>.
Ice detector controller switch to <u>TEST</u> then <u>MANUAL</u>.

2. Before takeoff checklist:

APU ISO valves <u>CLOSED</u>.
APU bleed valves <u>CLOSED</u>.
APU control switch to <u>STOP</u>.

III. TAKEOFF/CLIMB

A. PILOT/COPILOT ACTIVITIES

1. Lineup:

Pilot heat <u>ON</u>.
Angle of attack de-ice switch <u>ON</u>.
Anti-skid switch <u>ON</u>.
Set crosswind position knob 10.0°L.

2. Takeoff:

A/C pitch to 8° to 10° at 129(+3) knots.
Not over 13° until airborne, then up to 15°.

3. Initial Climb:

Landing gear lever <u>UP</u>.
(LEFT AFT MAIN LANDING GEAR FAILS TO RETRACT)
Crosswind reset switch <u>RESET</u> for 3 seconds.
Airspeed not less than 144 knots.

Flaps up at or above 166 knots (V_{MFR}).
No bank angle over 10° below 181 knots (V_{MFR}+15).
185 knots not exceeded with flaps of slats down.
A/S 250 knots when below 10,000'.

    4. S.I.D.:

Heading 010°($\pm$5°) from T.O. until angle of bank exceeds 15° for over 2 seconds.
When heading reaches 120°($\pm$5°), check 120°($\pm$5°) until intercepting SIE 284$\pm$5°R.
MAINTAIN SIE 284°($\pm$5°)R.
Altitude 5000' or below when crossing ATR 010°R.
When over SIE track outbound 143°$\pm$5°)R.
At 10,000' accelerate to 270($\pm$10) knots, hold until .7 mach.
At 18,000' adjust altimeter to 29.92.
Intercept B 24 route after weather deviation.

B. NAVIGATOR ACTIVITIES

    1. At 18,000' adjust altimeter to 29.92

    2. Navigate around weather at Berman to intercept B 24 route.

C. FLIGHT ENGINEER ACTIVITIES

    1. Initial Climb:

Air conditioning MASTER switch <u>LEFT</u>, <u>RIGHT</u>, <u>BOTH</u>.
Floor heat <u>ON</u>.
Engine anti-ice switch <u>ON</u>.
Regulator fail switch <u>TEST</u>.
Engine anti-ice switch <u>OFF</u>.
Ice detect switch <u>AUTO</u>.
PTUs <u>OFF</u>.
#1 and #4 hydraulic boost pumps <u>OFF</u>.

    2. Cabin Pressurization Malfunction:

(Note: System failed on ground but is detected at 3000' AGL.)

Mode Select Switch to <u>MANUAL</u>.
Controller knob to <u>INCREASE</u>.
Controller knob RELEASED at outflow valve position indication near CLOSED.

IV. ENROUTE PHASE

A. PILOT ACTIVITIES

    1. Leveloff:

Engage autopilot to leveloff at FL 290.
A/S.77(+.01)mach, 470(+10) knots TAS, 300(+10) knots IAS.

B.   NAVIGATOR ACTIVITIES

   1.   Leveloff fix:

        Enter select - FIX.
        Display select -FIX.
        Norm/Altn - NORM.
        CLR.
        Enter TACAN FP #1 and FP #2.
        ENT.
        Enter select - PRES POS.
        CLR.
        ENT.

   2.   Cruise:

        AHRU crosscheck:

             Enter select - PRES POS.
             Display select - SPECIAL DATA.
             Norm/Altn - NORM.
             CLR.
             Enter 300.
             ENT.

        Between Berman and Destination.

        IDNE LORAN FIX:

             Enter select - FIX.
             Display select - FIX.
             Norm/Altn - NORM.
             CLR.
             Enter master station fix # - xx3.
             ENT.
             Enter slave A station Fix # - xx1.
             ENT.
             Enter slave B station Fix # - xx2.
             ENT.
             Enter Select Switch - PRES POS.
             CLR.
             ENT.
             (Data Registers display LORAN Fix data.)

        IDNE Celestial Position fix:

             Enter select - FIX.
             Display select - SPECIAL DATA.

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Norm/Altn - <u>ALTN</u>.
<u>CLR</u>.
Enter GMT Hours - oxx.
<u>ENT</u>.
Enter GMT MINUTES and SECONDS - xx xx.
<u>ENT</u>.

At Berman:

(INERTIAL ERROR IS INTRODUCED.)
(North of Clark insert #1 Hydraulic quantity loss.)

Enter new navigational checkpoints (Eli, Smelt, Charleston):

Enter display at <u>PRI/AUX</u>.
Enter select - <u>DEST</u>.
Display select - <u>DEST</u>.
Norm/Altn - <u>NORM</u>.
<u>CLR</u>.
DP #xxo.
<u>ENT</u>.
DP latitude _____.
DP longitude _____.
Norm/Altn - <u>ALTN</u>.
Enter fuel time xx.x.
<u>ENT</u>.

Reinitiate Steering Mode:

Enter select - <u>PRES POS</u>.
Display select - <u>DEST</u>.
Norm/Altn - <u>NORM</u>.
<u>CLR</u>.
Enter DP #xxo.
<u>ENT</u>.
Depress TRACK or DEST STEER.

At Clark:
    Check ETA(+3) minutes.
    Within 5nm.

At Eli:
    Check ETA(+3) minutes.
    Within 5nm.

At Smelt:
    Check ETA(+3) minutes.
    Within 5nm.

After Smelt obtain RADAR FIX:

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Enter select - FIX.
Display select - FIX.
Norm/Altn - NORM.
CLR.
Enter Radar FP #xxo.

C. FLIGHT ENGINEER ACTIVITIES

1. Engine Vibration Check:

Madar Components ALL ON.
Engine #1 rent to 80% N2 RPM.
Access Film Frame:

Frame Address button Pushed.
#2051 Entered.
Ex button Pushed.

Select Frame for appropriate engine (#1):

Frame Address button Pushed.
#2052 Entered.
Ex button Pushed.

ODRU Check:
All knobs ALIGN or DETENT.

Enter CMA message:

CMA Message button Pushed
7 digit code Entered (8101908 for #1 engine).
Ex button Pushed.

Obtain ODRU display:

Single Sweep button Pushed.
Check readout on ODRU and film frame (non-measurable).

Obtain next procedure:
Frame Advance button Pushed.

Enter CMA Message:

CMA Message button Pushed.
7 digit code Entered (8101908 for #1 engine).
Ex button Pushed.

Obtain ODRU display:
Single Sweep button Pushed.

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Obtain next procedure:
    Frame Advance button Pushed.

Enter CMA Message:

    CMA Message button Pushed.
    7 digit code Entered.
    Ex button Pushed.

Obtain ODRU display:
    Single Sweep button Pushed.

Obtain next procedure:

    Frame Advance button Pushed.
    (Note: Engine Shutdown Procedures).
    (Note: End of Routine).

2. Hydraulic Failure: #1 System

    Top and bottom switches (engine driven pumps) to <u>DEPRESS</u>.
    #1 and #2 selector switches (F.E. Hydraulic Panel) to <u>OFF</u>.
    System #1 ATM switch (F.E. Hydraulic Panel) to <u>OFF</u>.

3. Generator Failure:

    Place generator control switch to <u>OFF</u>.
    Generator select switch to #1.
    CSD disconnect switch to <u>DISCONNECT</u>.

V. DESCENT/APPROACH/LANDING PHASE

    A. PILOT ACTIVITIES

        1. Enroute Descent:

            Nav. Selector Panel to <u>PRI COMPT</u> and <u>VDR</u>, <u>HDG</u>.
            BOHI to TACAN #1 VOR #2.
            Radar altimeter set to 1000'.
            Reset pressure altimeter passing FL 180.
            A/S under 300 knots above 10,000'.
            A/S under 250 knots below 10,000'.

        2. Holding:

            Enter holding at the holding fix (CHS 052/13)(+1)nm.
            A/S 206(+10) knots.

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3. Low Altitude Approach:

Before IAF:

>   Track CHS 052°R to 10nm.
>   A/S above 175 knots until 40% flaps.

At IAF:

>   Gear down with emergency extend switch.
>   A/S at or below 200 knots.

ARC:

>   Arc at 10(+1.5)nm.
>   Altitude 1800(+100)ft.
>   A/S with gear down 155(+10,-5) knots.

Final Approach:

>   Maintain 334°(+5°)R tracking inbound.
>
>   A/S 145(+10,-5) knots.
>
>   Altitude not less than 860 ft. until 3 nm.
>   Between 3 nm and station passage altitude not less than 440(+50)ft.
>   After flaps set to 100%, A/S to 125(+10,-5) knots.

Missed Approach (at station passage):

>   Throttles to TRT, Inflight EPR 4.89.
>   Flaps to 40%.
>   Pitch 8 to 10 up.

4. ILS:

>   Altitude not less than 1600(+100) until LOM.
>
>   A/S 125(+10,-5) knots at LOM.
>
>   Flaps 100% at LOM.
>   Azimuth within one dot deviation of CDI.
>   Glidepath within one dot deviation on VDI.

B. NAVIGATOR ACTIVITIES

1. Enroute Descent Checklist (verticle navigation data entry):

Enter display – PRI.
Enter select – DEST.

Display select - <u>VERT NAV</u>.
Norm/Altn - <u>NORM</u>.
Enter DP # and 0 or 1: xx0 or xx1.
Enter G.S at DP: -03.
<u>ENT</u>.
Enter DP ALTITUDE 44.
<u>ENT</u>.
Norm/Altn to <u>ALTN</u>.
Enter flare bearing: 149.0
<u>ENT</u>.

2. Holding:
Radar altimeter set to 200'.

3. After landing:

Checklist

MMR function selector switch <u>OFF</u>.
LORAN OFF.

Engine shutdown:

IDNE failure recall procedure:

Enter select switch <u>PRES POS</u>.
Display select switch <u>SPECIAL DATA</u>.
Enter display pushbutton Depressed for computer
in control.
<u>CLR</u>.
Enter 101.
<u>ENT</u>
<u>CLR</u>.
Enter 102.
<u>ENT</u>.
<u>CLR</u>.

IDNE OFF:
AHRU instrument ground switches <u>OFF</u>.

C. FLIGHT ENGINEER ACTIVITIES

1. Enroute Descent:
Pressure mode select switch to <u>LAND</u>.
#1 and #4 hydraulic boost pumps <u>ON</u>.

2. At IAF:
All PTUs <u>ON</u>.
Ice detector to <u>MANUAL</u>.

3. After Landing:

    Checklist:

            APU to <u>START</u>.
            APU bleed valves <u>OPEN</u>.
            APU isolation valves <u>OPEN</u>.
            APU generator select switch <u>LEFT</u> or <u>RIGHT</u>
            Buss tie switches to <u>GND X-FER</u> and back to <u>OFF</u>.
            Hydraulic pumps to <u>DEPRESS</u> and back to <u>NORM</u>.

    Engine Shutdown:

            Fuel boost pumps <u>OFF</u>.
            Augmentation air switches <u>OFF</u>.
            PTUs <u>OFF</u>.
            Floor heat <u>OFF</u>.
            Recirculation fan <u>OFF</u>.
            Fuel crossfeed valves <u>CLOSED</u>.
            Fuel isolation valves <u>CLOSED</u>.
            Separation valves <u>CLOSED</u>.
            Main tank fuel valves <u>OPEN</u>.
            Aux and external range refuel valves <u>REFUEL</u>.
            Auto refuel switch <u>MANUAL</u>.
            Engine anti-ice <u>OFF</u>.
            Ice detector switch <u>OFF</u>.

APPENDIX B

DISPLAY SYSTEMS CONSIDERATIONS

Flight Deck Layout

The instructor's space on the flight deck is quite cramped. An unseccessful search was made for good places to locate additional display monitors. Therefore, to upgrade the instructor's displays, the choice narrows to:

a. Utilize existing TV monitors and have the PMS generate displays on additional video channels.

b. Replace the TV monitors with either a random scan or a mixed media display system.

c. Add flat panel displays. Since plasma tube displays require only 8 inches in depth, it would be possible to locate these thin displays on vacant bulkhead space.

Display Technology

TV VIDEO – Currently the flight and navigator instructor's stations are outfitted with 14-inch TV monitors. Either may select a malfunction display or a route plot. A TV camera focussed on the flight recorder generates the route plot. A slide projector projects the route on the back of the flight recorder; a pen assembly plots the C-5 history on the front surface. The resulting video is cabled to the TV monitors on the flight deck.

The malfunction display video is generated by an alphanumeric scan converter attached to the TI 980B.

The following are potential modifications to the display system (while retaining the video technology):

a. Microfiche to video, or video disk medium to allow rapid retrieval of checklist or route chart images.

b. Computer- controlled graphic scan converter to allow C-5 history plots.

c. Video mixing devices to allow superposition of computer graphics (or alphanumerics) on top of background images (route charts, checkoff lists).

The limitations of the TV video approach are:

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a. Resolution - route charts may not be visible in sufficient detail.

b. Dynamics - computer graphics requiring rapidly changing images are generally done using random scan displays. Conversion equipment exists but normally requires some sacrifice in the dynamics of the display.

The advantages of the TV video approach are:

a. Gray scale.

b. Intensity.

PLASMA SCOPE - A relatively new display technology is the plasma scope which is sometimes referred to as the "flat panel display." Of significance is the ability to project microfiche images directly on the back panel. The computer can then superimpose graphics or text on top of the microfiche image.

The advantages of the plasma scope approach are:

a. Ability to superimpose computer graphics over static images.

b. Low-cost information retrieval.

The disadvantages of the plasma scope approach are:

a. Lack of gray scale.

b. Granularity of computer graphics.

c. Limited dynamics.

RANDOM SCAN REFRESHED GRAPHICS - This is the type of graphic display system most commonly used in simulators. AFTS selected these displays because of the requirement to replicate the attack display dynamics. On several similar random scan displays, the computer can draw instrumentation on the display face rather than requiring actual repeater instruments for instructor use.

The advantages of the random scan refreshed graphics are:

a. Display dynamics (animation).

b. Gray scale.

The disadvantages of the random scan refreshed graphics are:

a. Expense of media conversion.

b. Textured drawings as comples as aeronautical charts are beyond the capacity of most random scan displays.

c. Inability to mix media.

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